**Northeast Fisheries Science Center Reference Document 09-02b**

# The Northeast Data Poor Stocks Working Group Report

*December 8-12, 2008 Meeting*

## Part B. Weakfish

by Northeast Data Poor Stocks Working Group

*NOAA's National Marine Fisheries Service, 166 Water St., Woods Hole MA 02543-1026*

**U.S. DEPARTMENT OF COMMERCE**
National Oceanic and Atmospheric Administration
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# Northeast Fisheries Science Center Reference Documents

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**January 22, 2009**

# WEAKFISH

This report contains five Working Papers. They were provided to the Peer Review Panel of the Northeast Data Poor Stocks Working Group at the December 8-12, 2008 meeting in Woods Hole, MA. The Peer Review Panel was asked to provide guidance/suggest methodologies for scientists to use in future weakfish assessments. The Report of the Peer Review Panel is available at: http://www.nefsc.noaa.gov/nefsc/saw, under the heading "Northeast Data Poor Stocks Working Group, 2008."

| | |
|---|---|
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| **Working Paper 5** | **Questions regarding the Weakfish Stock Assessment for the Data Poor Stocks Working Group Review Panel** |

*This information was distributed solely for the purpose of pre-dissemination peer review at the December 2008 Data Poor Stocks Working Group Meeting. It is not being formally disseminated by NOAA and it does not represent any final agency determination or policy.*

Working Paper 1

# Weakfish Methodology

By

Jeffrey Brust
for
Weakfish Stock Assessment Sub-Committee

Data Poor Stocks Working Group Meeting
December 8-12, 2008
Woods Hole, MA

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**WEAKFISH WP#1. (11/24/08)**

***MEMORANDUM***

**TO:** Data Poor Working Group Review Panel Members

**FROM:** Jeff Brust, for Weakfish Stock Assessment Subcommittee

**RE:** Update to Weakfish Stock Assessment Methodology

Among the materials provided for your review of the weakfish stock assessment is the most recent peer reviewed assessment (ASMFC 2006), which includes the assessment (in two parts), the peer review report, and supplemental information requested by the ASMFC Weakfish Management Board. For the ongoing assessment, we are using very similar methodologies as those outlined in the 2006 peer reviewed assessment. However, there are some changes and updates ASMFC staff and the Stock Assessment Subcommittee felt would benefit from your review.

The attached report is a preliminary draft of portions of the stock assessment report, including management and assessment history, description of primary fisheries, and description of available fishery dependent and fishery independent data sources. Information contained in the current report is consistent with the text of the 2006 assessment, but the current report provides additional detail on certain aspects, such as the survey indices.

You will note certain sections of this draft are highlighted in yellow. This draft was developed prior to the Weakfish Data Workshop in July 2008. Highlighted text indicates sections that need to be updated based on discussions and decisions made during the July workshop. As these edits will not be done prior to the Data Poor Workshop, I would like to provide you with a list of some of the more substantial changes to input data that were decided on at the July workshop.

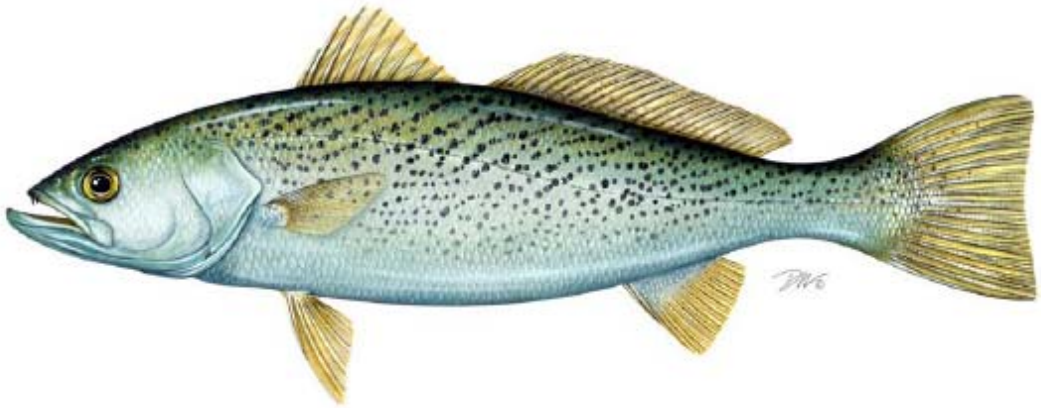
- Recreational weakfish catch (A, B1, B2) from Florida were "corrected" for sand seatrout and sand seatrout/weakfish hybrids
- The recreational discard mortality rate was decreased from 20% to 10%
- Recreational discard length frequency were assigned based on recent headboat discard data (previously, discards assumed the same size as harvest)
- Commercial discard rates have been updated with recent data
- New Jersey trawl index now based on delta log-normal for August cruise only (previously arithmetic mean for August and October cruises)
- Recreational index now based on all private boat trips in Mid-Atlantic (previously used only trips that caught a suite of species commonly occurring with weakfish)

Most of these changes could be made retroactive to 2000 (the most recent year age-length keys are available).

In addition to these changes to input data, I have requested the principle modelers for other candidate models to provide updates to changes in their methodology. These updates will hopefully be sufficient to allow you to adequately review the assessment as a work in progress. I look forward to discussing the

assessment and any recommendations you may have at the December Data Poor Working Group in Woods Hole.

# WEAKFISH STOCK ASSESSMENT REPORT



A Report of the ASMFC Weakfish Technical Committee

Presented to the 49th Stock Assessment Workshop
Stock Assessment Review Committee
Woods Hole, MA

June 2009

NOTE: ZZ Section prefix will be replaced with letter assigned to assessment by J. Weinberg.

## ZZ1.0 CONTRIBUTORS

ASMFC Weakfish Technical Committee and Stock Assessment Subcommitte:

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and

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## ZZ2.0 TERMS OF REFERENCE FOR WEAKFISH

1. Evaluate biases, precision, uncertainty, and sampling methodology of the commercial and recreational catch including landings and discards.

2. Evaluate precision, geographical coverage, representation of stock structure, and relative accuracy of the fisheries independent and dependent indices of abundance.

3. Evaluate the catch at age modeling methods and the estimates of F, spawning stock biomass, and total abundance of weakfish produced, along with the uncertainty of those estimates. Review the severity of retrospective bias. (This TOR will change following the stock assessment workshop in September.)

4. Evaluate the aggregated biomass modeling and index methods and the estimates of F, spawning stock biomass, and total abundance of weakfish produced, along with the uncertainty of those estimates. Determine whether these techniques, including predator-prey extensions, could substitute for age-based modeling for management advice. (This TOR will change following the stock assessment workshop in September.)

5. Review evidence for constant or recent systematic changes in natural mortality.

6. Estimate and determine the accuracy and precision of biological reference points.

7. Review stock projections and impacts on the stock under different assumptions of fishing and natural mortality.

8. Make research recommendations for improving data collection and assessment.

## ZZ3.0 EXECUTIVE SUMMARY

**ZZ3.1 Major findings for TOR 1 - Evaluate biases, precision, uncertainty, and sampling methodology of the commercial and recreational catch including landings and discards.**

**ZZ3.2 Major findings for TOR 2 – Evaluate precision, geographical coverage, representation of stock structure, and relative accuracy of the fisheries independent and dependent indices of abundance.**

**ZZ3.3 Major findings for TOR 3 - Evaluate the catch at age modeling methods and the estimates of F, spawning stock biomass, and total abundance of weakfish produced, along with the uncertainty of those estimates. Review the severity of retrospective bias. (This TOR will change following the stock assessment workshop in September.)**

**ZZ3.4 Major findings for TOR 4 - Evaluate the aggregated biomass modeling and index methods and the estimates of F, spawning stock biomass, and total abundance of weakfish produced, along with the uncertainty of those estimates. Determine whether these techniques, including predator-prey extensions, could substitute for age-based modeling for management advice. (This TOR will change following the stock assessment workshop in September.)**

**ZZ3.5 Major findings for TOR 5 - Review evidence for constant or recent systematic changes in natural mortality.**

**ZZ3.6 Major findings for TOR 6 - Estimate and determine the accuracy and precision of biological reference points.**

**ZZ3.7 Major findings for TOR 7 - Review stock projections and impacts on the stock under different assumptions of fishing and natural mortality.**

**ZZ3.8 Major findings for TOR 8 - Make research recommendations for improving data collection and assessment.**

## ZZ4.0 INTRODUCTION

This is the first update to the weakfish stock assessment since 2006 when the assessment was peer reviewed through the Atlantic States Marine Fisheries Commission (ASMFC) External Peer Review process. The 2006 assessment updated the stock through the 2003 fishing season. The current assessment includes harvest data and survey indices through 2007.

### ZZ4.1 Management Unit Definition

Weakfish stocks on the U.S. Atlantic coast are managed through the ASMFC Interstate Fishery Management Plan (FMP) for Weakfish. Under this FMP, weakfish are managed as a single unit stock throughout their coastal range. Historically, all states from Massachusetts through Florida had a declared interest in the species. Currently, however, Massachusetts, Connecticut, South Carolina, Georgia, and Florida maintain *de minimus* status.

### ZZ4.2 Management History

The first fishery management plan for weakfish was implemented by ASMFC in 1985 to address stock declines, bycatch concerns, the lack of sufficient data for management, and interstate user conflicts. The management measures under the FMP were voluntary and provided no benefit to the stock.

Amendment I, adopted in 1991, established a target fishing mortality rate of $F_{20\%} = 0.34$. This would be achieved by a 52% reduction in directed harvest, as well as reductions in bycatch mortality in the penaeid shrimp fisheries. Although adoption of turtle excluder devices (TEDs) in the shrimp fishery led to bycatch reductions, none of the states with directed fisheries adopted regulations consistent with the Amendment. Consequently, Amendment I was not successful at attaining the target fishing mortality rate.

Continued concern regarding the status of the weakfish stock (as a result of ASMFC fishery management regulations not being mandatory) was a major impetus for the development and passage of the Atlantic Coastal Fisheries Cooperative Management Act, which made compliance with ASMFC fishery management plans mandatory for member states. As an interim measure, the ASMFC approved Amendment II to the Weakfish FMP for implementation in April 1995. The provisions of Amendment 2 were mandatory and included harvest control strategies such as a 12” minimum size, maintaining current minimum mesh sizes, and bycatch reduction requirements. Fishing mortality would be reduced in a stepwise fashion, with a 25% reduction in harvest occurring in 1995 and the remainder occurring in 1996. The effects of Amendment II were positive, although below average fishery catch rates, a lack of older age fish, and below average spawning stock biomass indicated further improvements were necessary.

In response, Amendment III was developed to reduce fishing mortality to $F = 0.50$ by the year 2000, restore an expanded age structure, and restore fish to their full geographical range. Commercial fisheries were regulated by a combination of season and area closures, mesh regulations to minimize harvest of fish less than 12”, and stricter requirements for bycatch reduction devices (BRDs). The minimum recreational requirements were a 12” minimum size limit and four fish possession limit. States were allowed to implement alternate size and bag

limit regulations if they were conservationally equivalent to the minimum requirements. Bag limits were not required for minimum sizes of 16" or greater.

In 2000, a peer review of a stock assessment with data through 1998 indicated that weakfish biomass was high and fishing mortality rate was below the target of $F = 0.50$. Despite being ahead of schedule, it was recommended that low fishing mortality rates be continued to maintain an appropriate spawning biomass and promote expansion of stock size and age composition. Also as a result of the assessment, the Weakfish Technical Committee recognized several inconsistencies between management practices and stock dynamics. These could only be addressed through the development of a new Plan amendment. In the meantime, however, Addendum I to Amendment III was passed to maintain current regulations until approval of the new amendment.

Weakfish stocks on the U.S. Atlantic coast are currently managed under Amendment IV to the FMP. Although Amendment III was successful in reducing fishing mortality and increasing biomass, reference points established in Amendment III were too high to ensure sufficient spawning stock biomass. In addition, the reference period used to develop recreational management measures represented an overexploited stock (insufficient abundance of older, larger individuals). In response to these concerns, Amendment IV, passed in November 2002, established new fishing mortality and spawning stock biomass reference points, and adjusted the reference period to a period of greater stock health (1981 to 1985). Amendment IV establishes new reference points for fishing mortality target of $F_{target} = F_{30\%} = 0.31$, a fishing mortality threshold of $F_{threshold} = F_{20\%} = 0.5$, and a spawning stock biomass threshold of $SSB_{threshold} = SSB_{20\%} = 31.8$ million pounds. A fishing mortality rate greater than $F = 0.5$ constitutes overfishing, and the stock is considered overfished if SSB is less than 31.8 million pounds. If it is determined that the weakfish stock is overfished, Amendment IV requires ASMFC to implement measures to rebuild the population within 6 years (1½ generations).

Several addenda have been passed to improve management capabilities under Amendment IV. Addendum I was passed in December 2005 to modify biological sampling targets. Addendum III (May 2007) modified bycatch reduction requirements to maintain consistency with the South Atlantic Fishery Management Council. Of greater significance was passage of Addendum II in February 2007. A stock assessment conducted in 2006 showed a significant turn of events from previous assessment results (see full discussion in Section ZZ4.3, **Assessment History**). Model results indicated that weakfish stocks were at historic low levels, despite relatively low fishing mortality rates. A series of supplementary analyses indicated that the primary force behind the stock decline was interactions with other species, such as competition and predation. Projection analyses indicated that even with a full moratorium on harvest, stock rebuilding would occur slowly at best without a significant decrease in other sources of mortality. To minimize overall mortality without unduly penalizing fishermen, and to prevent expansion of the fishery in the event the stock begins to rebuild, Addendum II requires that all states 1) maintain current minimum sizes, 2) implement a recreational six fish bag limit, and 3) impose a 150 pound commercial bycatch trip limit. Addendum II also establishes triggers to re-evaluate these criteria. Commercial measures will be reconsidered when coastwide commercial harvest reaches 80% of the 2000-2004 average harvest. Commercial and recreational measures will be re-

evaluated when combined harvest for any state in one year exceeds 125% of their previous five year average.

### ZZ4.3 Assessment History

Early stock assessment analyses for weakfish were conducted using a variety of virtual population models, such as the Murphy VPA (ASMFC 1991) and CAGEAN. The first peer reviewed assessment analyzed data through 1996 using Extended Survivor Analysis (XSA). The peer review was conducted in 1997 by the Stock Assessment Review Committee (SARC) at the 26th Northeast Regional Stock Assessment Workshop (SAW). The Review Committee had concerns with the XSA model runs and requested updated runs as well as exploratory CAGEAN and ADAPT model runs. These were conducted, but there was insufficient time to fully review the results. As such, the review committee did not endorse the point estimates of *F* and SSB. Regardless, all models used indicated that SSB was increasing rapidly and fishing mortality rates were decreasing rapidly. SSB had increased an average of 22.5% per year since 1991, while *F* had decreased an average of 21.4% per year since 1990 (NEFSC 1998). The SARC concluded that continuation of low fishing mortality rates and good recruitment would allow for age expansion to a point comparable to that observed in the early 1980s.

The subsequent assessment, including data through 1998, was peer reviewed at the 30th SAW/SARC in 1999 (NEFSC 2000). The stock was assessed using the ADAPT VPA as recommended by the 26th SARC. Ages in recent years had begun to be taken from otoliths, which required a conversion of scale-based ages from earlier years to otolith-based ages. The approved VPA run included only indices from the core abundance area (New York to North Carolina). The model indicated that fishing mortality rates had declined to 0.21 in 1998, well below both $F_{MAX} = 0.27$ and $F_{MSY} = 0.6$. In addition, SSB had increased to about 39,000 metric tons, approximately 55% of an unfished stock. The SARC did observe a noticeable retrospective pattern, which overestimated stock size and underestimated fishing mortality in the last few years. Regardless, the Review Committee concluded that results of the ADAPT VPA could be used to calculate biological reference points, and that figures illustrating the expanded size and age composition of weakfish would be useful for developing management advice.

A stock assessment update was conducted in 2002 (with data through 2000) using the SARC approved methodology (ADAPT VPA with tuning indices from the core area; Kahn 2002). The assessment showed that estimates of fishing mortality decreased further to $F = 0.12$, while SSB increased to over 50,000 mt. Although this assessment was not peer reviewed, the Weakfish Technical Committee (TC) expressed concern about a strong retrospective pattern that resulted in high levels of uncertainty in recent year estimates. The committee recognized poor biological sampling of commercial catches, commercial discards, and recreational discards as a likely source of much of this error, especially when coupled with the assumption of error-free catch at age estimates used by ADAPT. Estimates of *F* and SSB were "corrected" by multiplying each parameter by the average amount each parameter changed in recent years with the addition of more data. Even so, the corrected estimate of $F = 0.23$ was substantially below $F_{Target} = 0.31$, and corrected SSB = 35,000 mt was more than double $SSB_{Threshold} = 14{,}428$ mt.

In 2003, the Weakfish Stock Assessment Subcommittee (WSAS) began preparation for a 2004 peer review through the 40th SAW. Model results using the SARC approved methodology still

exhibited a strong retrospective pattern, and results from both ADAPT VPA and biomass dynamic models indicated the stock was at very high levels (carrying capacity in the case of the biomass dynamic model; see Uphoff 2005) with very low fishing mortality. The Technical Committee was concerned that these results were not consistent with low catch rates being observed by commercial and recreational fishermen targeting weakfish.

For these reasons, the WSAS deemed the ADAPT VPA methodology as insufficient to characterize the weakfish resource and proceeded to investigate alternative assessment methods. Although the revised weakfish assessment was incomplete at the time of the SAW, the SARC agreed to review the work and provide guidance on issues that were impeding the progress of the assessment (such as the inconsistency between survey indices and fishery-dependent indices of abundance and catch at age).

The Review Committee agreed with the WSAS that the results of the work in progress, although using the same approach as the SARC-approved assessment in 1999, were not suitable for management. The Review Committee indicated that they felt the problem was conflicting data, and expressed skepticism about the reliability of some survey indices, especially the Northeast Fishery Science Center Fall Survey. Recommendations from the SARC proved to be useful, and some were incorporated into the stock assessment. The assessment was also expanded to include some alternative approaches previously explored by the WSAS in the 2002 update process. (ASMFC 2006, Part A)

The stock assessment was completed in February 2006 and submitted to ASMFC for evaluation through the ASMFC External Peer Review process. The Peer Review Panel consisted of four fisheries biologists with expertise in population dynamics and stock assessment methods. The Panel did not endorse the statements regarding weakfish stock status and identified several issues that required additional work or attention by the Weakfish Technical Committee before they would support its use for management purposes (ASMFC 2006, Part B). In particular, the Panel had concerns regarding stock structure, age composition data, and fishery discards.

The Weakfish Management Board directed the Technical Committee to address the issues identified by the Review Panel. Specifically, the Management Board tasked the Technical Committee with further investigating stock structure and discards; determining agreements and disagreements among the assessment report, the peer review panel report, and the 40$^{th}$ SARC report; and providing an account of the implementation of recommendations from the 40$^{th}$ SARC.

In August 2006, the Technical Committee provided a response to these tasks (ASMFC 2006, Part C). Based on these responses, the Technical Committee's analyses, and significant evidence, the Management Board accepted the following five points for management use:

1. The stock is declining;
2. Total mortality is increasing;
3. There is little evidence of overfishing occurring;
4. Something other than fishing mortality is causing the stock decline, and;

5. There is a strong chance that regulating the fishery will not, in itself, reverse the stock decline.

## ZZ4.4 Life History (Lee Paramore)

### *ZZ4.4.1 Reproduction*

### *ZZ4.4.2 Age and Growth*

### *ZZ4.4.3 Natural mortality*

### *ZZ4.4.4 Stock Definitions*

The weakfish range extends along the Atlantic coast from Massachusetts to southern Florida, although strays are occasionally found as far as Nova Scotia, Canada and into the eastern Gulf of Mexico. Primary abundance occurs between New York and North Carolina. Within their range there is evidence of multiple stocks. Munyandorero (2006; see ASMFC 2006, Part C) provides a concise but thorough overview of available information on weakfish stock structure. The following is an excerpt.

> Investigations of weakfish population structure along the US Atlantic coast have been undertaken through tagging, meristic, morphological, life history, genetic and otolith chemistry studies (Table 1). The conclusions reached are conflicting. While Crawford et al (1988), Graves et al. (1992) and Cordes and Graves (2003) did not detect genetic differentiation within the weakfish population, Chapman et al. (unpublished report) found that weakfish are made up of a series of overlapping stocks, without complete panmixia. Non-genetic studies found evidence of existence of multiple weakfish sub-populations (e.g., Nesbit 1954; Shepherd & Grimes 1983, 1984; Scoles 1990) or important spatial structure of the weakfish population (Thorrold et al. 1998, 2001). Mark-recapture, meristic, morphological and life-history studies (e.g., review by Crawford et al. 1988) indicated that weakfish could be partitioned into sub-stocks…

Crawford et al (1988) recommend that weakfish be managed as separate northern and southern stocks, while Graves et al (1992) recommend management of a single unit stock. The Weakfish Technical Committee reviewed the available information and reached the following conclusions.

- Evidence of stock structure exists
- Data is inadequate to define stock structure, and there is enough potential mixing that pinpointing the location of a north/south split is not possible at this time
- If a north to mid-Atlantic subpopulation is in serious decline, this does not warrant a north-south split based on conservation concerns (ASMFC 2006, Part C).

Based on those recommendations, the ASMFC Weakfish FMP continues to manage Atlantic coast weakfish as a single unit stock throughout their coastal range.

## ZZ4.5 Habitat description

Weakfish are found in shallow marine and estuarine waters along the Atlantic coast. They can be found in salinities as low as 6 ppt (Dahlberg 1972) and temperatures ranging from 17$^{o}$ to 26.5$^{o}$ C (Merriner 1976).

Like many other North Atlantic species, weakfish exhibit a north-inshore/south-offshore migration pattern, although in the southern part of their range they are considered resident. Shepherd and Grimes (1983) observed that migrations occur in conjunction with movements of the 16-24$^{o}$ isotherms. Warming of coastal waters during springtime triggers a northward and inshore migration of adults from their wintering grounds in the Mid-Atlantic. The spring migration brings fish to nearshore coastal waters, coastal bays, and estuaries where spawning occurs.

Weakfish spawn in estuarine and nearshore habitats throughout their range. Principal spawning areas are from North Carolina to Montauk, NY, although extensive spawning and presence of juveniles has been observed in the bays and inlets of Georgia and South Carolina. Larval and juvenile weakfish generally inhabit estuarine rivers, bays, and sounds, but have been taken in freshwater (Thomas 1971) and as far as 70 km offshore (Berrien et al 1978). Mercer (1983) found that juveniles are most prevalent in shallow bays and navigation channels and are commonly associated with sand or sand/grass bottoms.

Weakfish form aggregations and move southward and offshore as temperatures decline in the fall. Important wintering grounds for the stock are located on the continental shelf from Chesapeake Bay to Cape Lookout, North Carolina.

## ZZ4.6 Fishery description

### *ZZ4.6.1 Overview of fisheries*

#### *ZZ4.6.1.1 Commercial Fishery*

Records of commercial weakfish landings are available back to 1950 through the National Marine Fisheries Service (NMFS) website. From 1950 through the 1960s commercial landings ranged from about 2,000 to 4,000 metric tons (MT) per year (Figure ZZ4.6-1). Beginning in 1970, reported landings began a dramatic increase to a record high of more than 16,000 MT in 1980. From 1982 to 1988, landings fluctuated between approximately 8,000 and 10,000 MT. Except for a brief recovery in the mid- to late-1990s, landings have declined continuously from 1989 to the present. Estimated harvest in 2007 is the lowest on record at approximately 388 MT.

Throughout this period, three states - New Jersey, Virginia, and North Carolina - have consistently accounted for 70 to 90% of the coastwide total harvest (Table ZZ4.6-1; Figure ZZ4.6-2). North Carolina has predominated with nearly 37% of the coastwide harvest over the last ten years, while Virginia and New Jersey have averaged 25.6% and 17.0% respectively. During this same time period, New York has accounted for nearly 10% of coastwide harvest.

From the mid 1950s to the early 1980s landings from the trawl fishery generally accounted for 50 to 70% of total landings (Figure ZZ4.6-3). Beginning in the early 1980s, harvest from

trawlers began a gradual decline, and recently have accounted for approximately 20% of total harvest. Conversely, between 1979 and 1987, landings from gill nets increased from around 10% of annual harvest to 45% of annual harvest, and have remained relatively stable since that time. Over the entire time period, pound nets and haul seines have each averaged between 10 and 20% of total harvest annually, despite exhibiting generally negative trends over time.

Discarding of weakfish by commercial fishermen is known to occur, and discard mortality is assumed to be 100%. De Silva (2004) provided the first quantitative analysis of weakfish discards. Most discarding occurs in conjunction with two gears (trawls and gillnets) and a limited number of target species. Prior to 1996, discards are assumed to have occurred for non-regulatory reasons because few regulations were in place to limit the fishery. Since 1996, both regulatory and non-regulatory discarding has occurred. Regardless, population removals as a result of commercial discarding appear to be minor relative to harvest, even in recent years as harvest has decreased. (ADD SPECIFICS FROM RECENT YEARS AFTER UPDATE JANAKA'S WORK)

*ZZ4.6.1.2 Recreational Fishery*

Recreational harvest statistics for the weakfish fishery are available on the NMFS Marine Recreational Fishery Statistics Survey (MRFSS) website for the period 1981 to 2007. From 1981 to 1988, the number of weakfish caught and the number harvested fluctuated without trend between 2 million and around 11 million fish; however, during this same time period, harvested weight generally declined from around 16 million pounds to 6 million pounds (Figure ZZ4.6-4). During this time period, nearly 90% of all fish caught were retained.

From 1989 to 1993, catch (numbers) and harvest (numbers and weight) remained relatively stable. Catch fluctuated between 1.6 and 2.2 million fish, while harvest ranged between 0.95 and 1.8 million fish and 1.1 to 2.2 million pounds. The harvest ratio during this period decreased from around 90% to less than 50%. CORRECT MRFSS ESTIMATES FOR FL SEATROUT

In 1994, weakfish catches increased and averaged around 6 million fish until 2000. Harvest numbers increased to a lesser extent and fluctuated between approximately 1.5 and 2.5 million fish. Harvest weight also increased to a relative peak of 4 million pounds during this period. By 2003, all statistics had declined to at or near time series minima and have remained relatively stable. In 2007, total catch was 2.01 million fish, with a harvest of 0.58 million fish and 0.69 million pounds. Since 1994, harvest ratios have fluctuated between approximately 20 and 40% of all fish caught.

The recreational fishery has been dominated in the last fifteen years or so by New Jersey, accounting for 40 to 50% of total harvest (Table ZZ4.6-2). Since 1995, several states have each had periods of substantial landings, with Delaware contributing 20-30% of total harvest for 1995-1998, Maryland accounting for approximately 25% from 1999 to 2001, and North Carolina averaging 22.5% from 2003 to 2007. From 1995 to 2004, Virginia consistently harvested between 10 and 20% of coastwide harvest, but has decreased in recent years.

From 1981 to 1990, recreational harvest decreased from around 35% of total (commercial and recreational) harvest to approximately 15% (Figure ZZ4.6-6). Since 1990, harvest from the

recreational fishery has gradually increased, reaching a peak of approximately 58.5% in 2005 but dropping back to around 45% in 2006 and 2007.

Recreational discard mortality is assumed to be 20% of all discarded fish. Change to 10%, provide justification, references From 1981 to 1989, the proportion of landings to catch averaged 89%. Even with high landings, discard mortality was lowest of the time series, with all but one year having fewer than 200,000 fish. Between 1989 and 1995, harvest to catch ratio dropped drastically to the second lowest value (27%), and the number of dead discards increased to more than 800,000 in 1995. Harvest to catch ratio rebounded slightly to 41% in 1997 and 1998, but has since dropped back and has varied between 20 and 40% since 1999. Despite relatively stable discard rates since 1995, the number of dead discards has varied greatly due to large interannual fluctuation in catch. Discard mortality reached a peak of more than one million fish in 1996, with nearly equal values in 2000, but have since decrease along with catch. For the last five years, discard mortality has ranged between 250,000 and 500,000 fish.

### ZZ4.7 Current status

Throughout the 1980s and early 1990s, weakfish stocks experienced unsustainably high fishing mortality rates, which led to a decline in abundance into the 1990s. Amendments II and III were successful at reducing fishing mortality, and an increase in biomass was evident in the late 1990s. The most recent assessment indicates that fishing mortality has remained low under Amendment IV, yet weakfish biomass has dropped back to near historic low levels by 2003. Available evidence indicates that interspecific interactions are the primary cause for the biomass declines (ASMFC 2006, Part A). A peer review of the stock assessment did not endorse the statements regarding weakfish stock status and identified several issues that required additional work or attention by the Weakfish Technical Committee before they would support its use for management purposes (ASMFC 2006, part B). In particular, the Panel had concerns regarding stock structure, age composition data, and fishery discards. In August 2006, the Technical Committee responded to the peer review panel's concerns (ASMFC 2006, Part C). Based on these responses, the Technical Committee's analyses, and significant evidence, the Weakfish Management Board accepted the following five points for management use:

1. The stock is declining;
2. Total mortality is increasing;
3. There is little evidence of overfishing occurring;
4. Something other than fishing mortality is causing the stock decline, and;
5. There is a strong chance that regulating the fishery will not, in itself, reverse the stock decline.

# ZZ5.0 EVALUATE BIASES, PRECISION, UNCERTAINTY, AND SAMPLING METHODOLOGY OF THE COMMERCIAL AND RECREATIONAL CATCH INCLUDING LANDINGS AND DISCARDS. (TOR #1)

## ZZ5.1 Commercial

### *ZZ5.1.1 Landings*

Commercial landings data were taken from two sources. Where available, state-specific harvest records collected through a mandatory reporting system were considered the most reliable source for landings. Unfortunately, not all states require mandatory reporting of weakfish harvest. In such cases, landings estimates were obtained from the NMFS commercial landings database, available through the NMFS Office of Science and Technology, Fisheries Statistics Division website (*http://www.st.nmfs.gov/st1/*). Although estimates are available from NMFS, it is not mandatory to report weakfish harvest to NMFS. Discrepancies between NMFS reported harvest and state reported harvest under mandatory reporting suggest that NMFS harvest estimates for weakfish are a potential source of uncertainty. In an attempt to quantify the uncertainty between the two reporting systems, state reported landings from Delaware and Virginia were compared to federally reported landings in these two states for the period 2004 to 2006. Combined across all gears, NMFS reported landings for a given year differed from state landings by less than 10% in all instances except Virginia in 2006, when the difference exceeded 23% (Figure ZZ5.1-1). However, when evaluated at the gear level, more than one-third of all year/state/gear combinations differed by more than 20%, and in three cases exceeded 100% (Figure ZZ5.1-2). Generally speaking, then, annual estimates of weakfish harvest reported by state and federal agencies are relatively consistent when combined across all gears, but the allocation of landings by gear exhibit moderate to severe uncertainty.

#### *ZZ5.1.1.1 Biological samples*

Commercial biological samples include lengths, weights, and ages from state-specific port sampling programs. Commercial samples were combined with similar data from recreational and fishery independent sources to develop length-weight relationships and age-length keys (ALK) for use in the estimation of commercial catch at age.

*Lengths*

Commercial length data were used for two primary purposes: the development of length-weight equations and characterizing the distribution of commercial catches by length and age. Because a combination of both total length and fork length data were available, lengths were standardized to fork length measurements. A conversion factor was developed using data pooled across all sources for 2004 to 2006. Total length was converted to fork length using the equation

$$FL = (TL + 5.8106) / 1.0437$$

Length-weight equations were developed as in the 2006 assessment (ASMFC 2006, Part A). Length and weight data from all sources were pooled, and relationships were developed by region/year/season. Sample sizes and parameter estimates are presented in Table ZZ5.1-1.

Characterization of fishery catch at size was conducted using the same methods as the 2006 assessment (ASMFC 2006, Part A). Length frequencies were stratified by region/year/season/state/gear and applied to catch at the same level of stratification. Length-weight estimates were used in conjunction with length frequency distributions to convert estimates of harvested weight to a weighted estimate of harvested numbers at size (Quinn and Deriso 1999). Landings not identified to specific gear were pooled at the region/year/season level and classified as "other". In addition, cells with minimal landings (< 1% of region/year/season total) generally had insufficient sample size (see below) to characterize that fishery. These cells were pooled with landings from the "other" gear category and characterized using all available samples for that region/year/season.

Sample size and ratio of sample size per metric ton of landings were used to evaluate adequacy of sampling intensity. It was determined that a minimum sample of 30 lengths per stratum (region/year/season/state/gear) was required to adequately characterize a fishery. Strata with fewer than 30 samples were characterized using data substituted from a representative stratum with sufficient sample size. The minimum of 30 samples is much lower than sample sizes suggested in recent literature (Miranda 2007; Vokoun et al 2001). Insufficient sampling would tend to introduce uncertainty into the catch at size estimates; however, these studies recommend sample sizes necessary to meet an objective (characterizing entire population) much different than the current analysis (characterizing harvest of specific gear). Miranda (2007) notes that distributions with a smaller size range require a smaller sample size. Considering minimum size limits and gear selectivity, the sample size required to characterize a fishery is likely lower than those in published literature. Vaughan (2000) reports that a generally accepted level of sampling during SAW/SARC reviews is 100 fish per 200 MT of landings. A minimum sample size of 30 fish per stratum typically results in thousands of fish per 200 metric tons of landings for strata with direct or substituted samples.

Not all states collect sufficient commercial length frequency data to characterize their fisheries. For strata with insufficient length samples, data were substituted from the next most appropriate stratum. In most cases, substituted data came from the same region/year/season, but was substituted from another state and/or gear (TABLE of CAA substitutions). Care was taken to minimize differences in gear selectivity, and when necessary substituted data were truncated to account for differences in minimum size between the two states. Regardless, the Technical Committee recognizes that substituted data are not always representative of the stratum to which they are applied, resulting in uncertainty in the length frequency distribution of the catch. Of greatest concern are the geographic differences in fish size, coupled with the general lack of samples north of Delaware. In the northern part of their range, weakfish generally attain much larger sizes than in central and southern regions. As such, minimum sizes and average size of harvested fish are much larger in the northern portions of the range. When commercial samples from these states are insufficient and data are substituted from more southern states, the effect is an underestimation of the proportion of large fish in the harvest. In 2006, New Jersey began collecting commercial biological data. These data will serve to better characterize landings from this key state, and likely be more representative of catches in this region, decreasing uncertainty in catch at size estimates. Potential effects of these substitutions are explored in greater detail in Brust (2007, in prep). SUMMARIZE THEM HERE.

In summary, uncertainty in length data can be introduced both by sample size and substitution of data from alternate strata. Although sample sizes are generally less than recommended to characterize the length distribution of a population, they are much higher than levels commonly accepted as necessary to characterize a fishery. A minimum sample of 30 fish per stratum was considered an appropriate compromise between uncertainty due to low sample size from the stratum in question and uncertainty of samples from a substituted stratum.

For the southern region, characterization of the fisheries was done slightly differently. Commercial sampling in North Carolina includes collection of both lengths and weights, so it was possible to develop an average fish weight by gear and season for each fishery. The average weight was applied to the harvest weight to estimate number harvested. The number harvested was then partitioned to catch at size using the length frequency distribution of the samples. Florida, the only other southern region state with landings, collects no biological samples. Biological sample data from North Carolina were used as proxy information for Florida landings.

*Ages*

The principle use of age data is in the development of age-length keys. Sample sizes of ages by year, season, and source are provided in Table ZZ5.1-2. Prior to 1990, ages were based on scale samples. During the 1990s, otoliths became the principle method for aging weakfish. For the 1998 stock assessment, scale-based ages in previous years were converted to otolith-based ages using a scale-otolith conversion matrix (similar to an age-length key) based on direct comparison of approximately 2,300 samples (Daniel and Vaughan 1997; NEFSC 1998). Uncertainty in either aging method, as well as in the scale-otolith conversion matrix would be propagated through the catch-at-age matrix.

Age-length data from all available sources (commercial, recreational, fishery independent) were pooled by region/year/season to develop stratum specific age-length keys (four keys per year) as described by Vaughan (2000). Length intervals with missing information in the keys were filled by either averaging age distribution for lengths above and below, substitution from another stratum, or interpolating age distribution across several length bins. Results of the catch at size analyses were combined across states and gears within a region to develop estimates of harvest numbers at size by region/year/season.

### *ZZ5.1.2 Discards*

Commercial discards were estimated using the ratio estimation method described in de Silva (2004). Data from the NMFS Observer Database were queried to identify a suite of target species and gears most commonly associated with weakfish discards. The suite of target species was then subset using principle component analysis to minimize duplicate counting. Where available, trip or haul level estimates of discarded weakfish weight and target species harvest weight were used to develop annual ratios of gear/species-specific discard ratios. Ratios for the southern region (NC – FL) were considered insignificant, and the remainder of the analysis was conducted only for the northern region. Gear-species discard ratios were applied to harvest estimates by year/species/gear to estimate total weakfish discard weight by year/species/gear. Weakfish discard length frequency data by gear (all species combined) were used to convert discard weight to discard at size. Annual estimates by gear were partitioned into seasonal

estimates by using the proportion of annual landings by season and gear from the NMFS landings database. Gear-season discards at size were summed across gears and converted to seasonal discards at age by applying the appropriate seasonal ALK.

NEED TO UPDATE THIS PARAGRAPH For the current assessment, weakfish discard to target species harvest ratios were not calculated for 2004 to 2006. Instead, the average gear-species ratio for 2001-2003 were applied to each year. Also, discard length frequencies from gillnet trips were extremely low for 2004-2006 (Table of N). As a substitute, combined gillnet length frequencies from 2002-2006 were applied to all years from 2004 to 2006. As with the 2006 assessment, all discards were assumed to be discarded dead and were added to the overall catch at age matrix.

## ZZ5.2 Recreational

### *ZZ5.2.1 Landings*

Recreational landings data were obtained from the NMFS Marine Recreational Fishery Statistics Survey (MRFSS) database, which is available through the NMFS Office of Science and Technology, Fisheries Statistics Division website (*http://www.st.nmfs.gov/st1/*). MRFSS provides estimates for three subcategories of catch, including observed harvest (Type A), unobserved harvest (*e.g.* filleted before observation, discarded dead; Type B1) and discarded alive (Type B2). Estimates of harvest were developed for each region/year/season combination as a sum of observed and unobserved harvest (Type A + B1).

Precision in recreational catch and harvest estimates are calculated as a percent standard error (PSE). Lower values indicate better precision, and PSE values less than 20 are generally considered "acceptable" (NEFSC 1998). However, a recent review of the survey identified several potential biases and inadequacies of the sampling and estimation methodologies (NRC 2006; see http://www.nap.edu/catalog.php?record_id=11616). These include the inability to interview anglers at private access sites; the increasing use of household cell phones which are unavailable to the telephone sampling frame; reliance on unverified assumptions; and differences in statistical properties of data collected through different survey methods. The effects of these biases on estimates of recreational catch, harvest, and discards can not easily be quantified, leading to uncertainty in MRFSS recreational estimates. This uncertainty applies to all catch types over the entire time series, which has been collected using the same general methodology throughout.

#### *ZZ5.2.1.1 Biological samples*

Biological samples collected by MRFSS include lengths and weights of a subsample of Type A fish. No ages are collected from the recreational fishery. Recreational length-weight data were combined with similar data from commercial and fishery independent sources to develop length-weight relationships (see section ZZ5.1, Commercial). Length data were also used to partition harvest into harvest at size. Because of small sample sizes (Table ZZ5.1-2), length observations were pooled by region/year/season to expand harvest estimates at the same level of stratification. Unlike commercial data, estimates of recreational harvest in numbers are directly available from

the MRFSS website. Catch at size was estimated as the proportion measured at size by stratum multiplied by the estimated harvest (A+B1 fish) for that stratum.

The number of length samples collected by MRFSS is very low, but is still above the generally accepted level of 100 lengths per 200 mt of landings. Regardless, limited length samples may introduce error into the characterization of the fishery landings.

*ZZ5.2.1.2 Catch at Age*

Catch at age estimates for the recreational sector were calculated using similar methods as the commercial CAA (Section 5.1.2.1), except that estimates of harvest numbers were directly available from MRFSS, and estimating catch at size did not require stratifying to the state and gear level. Total harvest number by region/year/season was partitioned into numbers at size using appropriate length frequency distributions. These were converted to recreational catch at age by applying the appropriate ALK. Annual recreational harvest at age was found by summing across regions.

### *ZZ5.2.2 Discards*

Estimates of the number of recreational weakfish discards (Type B2 fish) were obtained from the MRFSS database. As in previous assessments, discard mortality is assumed to equal 20% of all discards. Since discarded fish are not observed by creel samplers, no biological data are available. In the absence of direct information, length frequencies of discards are assumed to be the same as observed (Type A) fish, and discard mortality at size is characterized using these data. The lack of direct observations of length frequencies of discarded fish contributes uncertainty into estimates of harvest.

## ZZ5.3 Catch Matrix Development

The catch-at-age matrix for 2004-2007 was developed using the same general procedure used in previous assessments. Catch at size from the four major sources of removals (commercial harvest, commercial discards, recreational harvest, recreational discards) were combined by region/year/season. ALKs for the corresponding stratum were applied to pooled catch at size to estimate catch at age. Results were pooled across regions and seasons to estimate total annual removals at age.

As described in each of the pertinent sections, there are several potential sources of uncertainty in the overall catch at age estimates. These include inaccurate harvest/discard estimates as a result of under/over reporting or inappropriate survey methods; insufficient sample size to characterize the length frequency distribution of a fishery; errors in aging techniques or the scale-otolith age conversion; substitution of data from alternate cells in the catch at size characterization and age-length keys; and others. Attempts have been made to quantify some of these error sources; however, the extent of uncertainty associated with each of these sources, and their cumulative effect, remains largely unknown. A persistent cumulative trend in either direction would result in inaccurate catch at age estimates and may influence assessment results.

NEED EFFORT DATA FOR COMM AND RECR FISHERIES

# ZZ6.0 EVALUATE PRECISION, GEOGRAPHICAL COVERAGE, REPRESENTATION OF STOCK STRUCTURE, AND RELATIVE ACCURACY OF THE FISHERIES INDEPENDENT AND DEPENDENT INDICES OF ABUNDANCE.

## ZZ6.1 NEFSC Bottom Trawl Survey

The National Marine Fisheries Service (NMFS) Northeast Fishery Science Center (NEFSC) conducts seasonal trawl surveys between Nova Scotia and Cape Hatteras. Stratified random sampling is conducted using a #36 Yankee otter trawl equipped with roller gear and a 1.25 cm mesh codend liner. The survey covers a large portion of the geographic range of weakfish, including their "core" distribution area (NEFSC 1996) of New Jersey to North Carolina. Despite the extended latitudinal range, the survey is not capable of sampling in shallow waters, and few sites are conducted in waters less than 9 m. In addition, the survey does not sample the South Atlantic portion of the range.

Weakfish are infrequent in the winter, spring, and summer surveys, but are commonly intercepted in the fall during their offshore migration. Because weakfish are rarely caught in this survey north of New Jersey the 26th SAW/SARC recommended developing an index of weakfish abundance using only strata from the south end of Long Island to Cape Hatteras during the fall survey. USE NJ to NC index Indices at age are developed by applying annual length frequency data from the survey to the annual mean catch per tow and then applying appropriate age-length keys. (What ALKs are used? Are they survey specific YES, when available!) During 1982 – 1990, the keys were coastwide. Since 1991, the keys used were developed from the Mid-Atlantic region. Because this survey occurs in the fall, true ages are increased by one year to develop an index of abundance on January 1 of the year following the survey (*e.g.* fall 1997 age 0 fish are treated as January 1, 1998 age 1 fish).

The annual mean catch per tow appears nearly cyclical, with relative peaks in abundance generally every 4 to 6 years (FIGURE). From 1981 through the mid 1990s, mean catch per tow cycled without trend, generally ranging between 40 and 120 fish per tow. Beginning in the mid 1990s, abundance gradually increased to a time series maximum of approximately 500 fish per tow in 2004. During 2005 – 2007, abundance decreased to about 200 fish per tow, but increased in 2008 to over 300 fish per tow. Standard error (SE) shows a similar pattern as CPUE, with an overall cyclical pattern and a gradual increase beginning in the mid 1990s. During the early portion of the time series, SE varied between approximately 10 and 50, increasing to a peak of 90 in 2004. Coefficient of variation (CV; SE as a ratio of the mean) has varied without trend between approximately 0.1 and 0.4 since 1990.

The survey index is dominated by age 1 fish (age 0 fish progressed to age 1), although fish have been observed out to age 6. Age distribution was greatest in the early 1980s, but was truncated to predominantly ages 1-3 by the early 1990s. Age distribution expanded somewhat during the late 1990s as the stock began rebuilding as a result of management measures, but has since declined to primarily ages 1-4.

The Technical Committee has expressed concerns that the NEFSC fall survey is not a good indicator of weakfish abundance. The timing of the survey, along with the highly contagious

distribution of weakfish, leads to high variability between years and between tows within a year. The Technical Committee is also concerned about the survey's ability to capture larger/older fish. The New Jersey trawl survey, which occurs in the months before and after the NEFSC survey in nearly identical strata (see below), catches a substantially larger proportion of large fish than the NEFSC fall survey(Figure). Finally, catch curve analysis shows in several instances year class abundance increasing over time (TABLE 3 of ASMFC 2006, Part 1). For these reasons, the TC has concluded that the NEFSC fall survey not be utilized as an "aged" or biomass index. What about utility as a YOY index, or as a composite index. What is size range of survey and size range of age 1 and/or age 2 fish?

TC Recommendation?? Not for aged index, not for biomass index, possibly for YOY (needs more evaluation). Problem with dropping is lose coastwide index and lose early part of time series (only survey that goes back to 1981). Being used to help estimate avg weight of discarded fish in recr fishery.

### ZZ6.2 New Jersey Ocean Trawl Program

New Jersey has conducted a stratified random trawl survey in nearshore ocean waters (0 to 90 feet) from Ambrose Channel (entrance to New York Harbor) to Cape Henlopen Channel (entrance to Delaware Bay) since 1988. The survey originated as bi-monthly cruises, but since 1991 has consisted of five cruises per year (January, April, June, August, and October). Strata are nearly identical to those used by NEFSC in this region (New Jersey's northern- and southern-most strata are truncated at New Jersey state boundaries). The gear used is a two-seam trawl with a 25 m headrope and 0.25" bar mesh codend liner. Due to funding constraints, several different vessels have been used to conduct the survey.

The geographic range of the survey is limited to nearshore ocean waters of the species distribution within the northern and southern borders of New Jersey. The survey occurs within the region sampled by the NEFSC trawl survey. The use of a smaller vessel, however, allows the New Jersey survey to provide better coverage in shallow waters.

The majority of weakfish are observed during the June, August and October cruises, although catches in June are inconsistent. An index of weakfish abundance is therefore developed using the August and October cruises. Since 1991, length frequencies have been aged using pooled (fishery dependent and fishery independent) late season ALKs from the northern region. Because the survey occurs in the fall, indices at age are progressed forward one age to indicate abundance on January 1 of the following year.

From 1989 to 1994, abundance was relatively stable between 20 and 40 fish per tow. Since 1995, abundance has varied much more widely and exhibits a similar cyclical nature as the NEFSC survey. The time series minimum of 5.72 fish per tow occurred in 1999, while the maximum of over 200 fish per tow occurred in 2005. SE has followed a similar trend as the mean over the time series, and CV has varied without obvious trend, ranging from approximately 0.2 to 0.5. (FIGURE)

From 1989 to 1995, the catch consisted primarily of ages 1-3, with ages 4-6 making up generally less than 10% of the total. Throughout the 1990s, age structure expanded, and in 1998 and 1999,

fish ages 4 and older accounted for more than 30% of the total CPUE. Since the turn of the century, age structure has again contracted, with older ages falling to less than 10% of the total since 2006. Regardless, the proportion of age 4 fish in the catch is generally higher now than it was during the early portion of the time series.

The Technical Committee has expressed concern that this survey suffers from some of the same shortcomings of the NEFSC fall survey. In particular, tow-level and annual mean catches show great variability, and catch curve analysis resulted in negative estimates of mortality for some year classes. Other concerns? The Technical Committee has therefore determined that the New Jersey trawl survey should not be used as an aged-index of weakfish abundance.

TC Recommendation?? Keep as is, but also investigate pos tows index; Uphoff's other indices are biomass based

### ZZ6.3 Delaware DFW Delaware Bay Trawl Survey

The Delaware Division of Fish and Wildlife has conducted a trawl survey within the Delaware Bay intermittently since 1966 (1966-1971, 1979-1984, and 1990 – present). The survey collects monthly samples (March through December) at nine fixed stations throughout the Delaware portion of the Bay. The net used has a 30.5 foot headrope and 2" stretch mesh codend. For the current assessment, only the 1981-1984 and 1990-present time series are evaluated. Weakfish abundance is calculated as an average number of age 1+ fish per nautical mile for June to October cruises, and the index is treated as a mid-year abundance. Since 1991, length frequencies have been aged using survey specific age-length keys.

The geographic range of this survey is limited to the Delaware Bay, a very small portion of the weakfish stock range; however, the Bay is known to be a major spawning ground for weakfish on the Atlantic coast (REFERENCE). As the survey occurs monthly for a large portion of the year, fish from a wide size and age distribution are available to the survey, from young of year to large older spawners.

Weakfish abundance was moderate in the early 1980s and early 1990s (approximately 15-30 fish/nm). Beginning in 1992, abundance increased sharply to a time series high of over 233 fish in 1996. Abundance decreased by more than half in 1997, and has exhibited a generally declining trend since that time. CV of the composite index showed relatively high variability from 1991 to 1995, ranging from 0.2 to 0.6. Interannual variability in CV stabilized in 1995 and generally ranged from 0.19 to 0.26 until 2001. Since 2001, CV has shown a slight increase, estimated at 0.33 in 2006. (FIGURE)

Age structure advanced from primarily age 1 and 2 fish in the early 1990s to include ages 7 and 8 in 1998-2000. Abundance of age 4+ fish accounted for 30 to 35% of the total index in 1997 and 1998 as the large 1993 year class moved through and benefits of previous regulatory actions were realized. Abundance of older ages has since declined to levels observed in the early 1990s, with 4+ fish accounting for less than 1% of the total.

The Delaware 30-foot trawl survey occurs in one of the major weakfish spawning areas and has been shown to capture a wide size and age range of weakfish throughout the year. Trends in

abundance correspond well with anecdotal and observed information from commercial and recreational fisheries. The Technical Committee has determined that the Delaware 30-foot trawl survey provides a reliable index of weakfish abundance. However, due to lack of older fish over most of the time series, abundance at age indices are restricted to ages 1 through 4.

TC Recommendation?? Keep it, ages 1 through 6+

### ZZ6.4 SEAMAP Fall Survey

The Southeast Area Monitoring and Assessment Program (SEAMAP) has conducted three seasonal trawl surveys since 1989 between Cape Hatteras, NC and Cape Canaveral, FL. A stratified random design is employed to sample inner (4.6 to 9.1 m) and outer (9.1 to 18.2 m) depth strata using twin 75-foot highrise mongoose trawls towed behind a double rigged St. Augustine shrimp trawler. The geographic range of the survey encompasses nearshore ocean waters south of Cape Hatteras, and SEAMAP is the only fishery independent survey conducted in the southern portion of the weakfish range. Unfortunately, catches of weakfish south of North Carolina are extremely small and of little value as an index of abundance. An index of abundance is therefore generated using only strata off North Carolina during fall cruises. Survey length frequencies are aged with annual late-season keys from 1989-1990, and annual late-season South Atlantic keys since 1991. The keys were developed from pooled commercial and research samples. Survey specific ages where available, otherwise use south late key (primarily NC data). Fall aged fish are progressed one age to estimate January 1 abundance in the following year.

Until 2002, the survey index varied without trend, ranging from approximately 5 to 30 fish per tow, with the exceptions of 1993 with an index of less than 1 fish per tow, and 1994 and 1995 with indices of approximately 44 and 52 fish per tow. From 2003 to 2005, the index increased to between 35 and 60 fish per tow, before jumping drastically to nearly 500 fish per tow in 2006. In 2007, the index dropped back down to 45 fish per tow. (FIGURE)

Survey variability and precision? (updated in trawl surveys.xls)

Age structure is truncated in the survey catch-at-age matrix, and the survey is driven primarily by age 1 and age 2 fish. Barring the 2006 index value, strongest recruitment (age 1) events occurred in 1995 and 2003. The 2006 index is anomalously high, with an age 3 index greater than the age 1 index in most years. Age 4+ fish generally constitute less than 1% of the total catch, with a maximum of 11.2% in 1998 and 7.7% in 1999 as the strong 1994 year class moved through.

TC recommendation? Need catch curve analysis (Des, send data), pres/abs, geo mean (Jim, send him the data), review and present all strata/states, discuss concerns (sand seatrout etc an justify which data we use based on concerns and analyses ; possible vessel problems in 2007 may have delayed survey or stopped sampling. If add in other non-core surveys, can still justify keeping southern SEAMAP stations out because of sand seatrout concerns

### ZZ6.5 Massachusetts DMF Trawl Survey

The Massachusetts Division of Marine Fisheries conducts a stratified random trawl survey in six depth zones (0-30, 31-60, 61-90, 91-120, 121-180 and >180 feet) and five geographic regions within the state. Sampling has been conducted twice per year (May and September) since 1978. Survey gear consists of a two-seam whiting trawl with a 39 foot headrope and a 0.5" stretch mesh codend liner. Weakfish, primarily young of year, are most commonly observed during the fall survey in the three regions south of Cape Cod. Mean catch per tow is used as an index of young of year abundance in the survey year.

The MA DMF trawl survey area encompasses nearshore ocean and estuarine areas within Massachusetts state boundaries. Like the New Jersey trawl survey, the survey area overlaps a portion of the NEFSC trawl survey area, but a smaller vessel allows more comprehensive sampling of shallow waters. Although large numbers of weakfish have been observed in Cape Cod Bay and Massachusetts Bay (Collette and Klein-MacPhee 2002), these waters are generally considered the northern extent of the weakfish range.

Mean annual catch per tow is consistently under 2 fish, with only three exceptions since 1981. Abundance generally declined from 1981 to 1984. In 1985, abundance increased more than 100-fold to the time series high of more than 15 fish per tow. Recruitment was again relatively high in 1986 (2.7 fish per tow), before dropping back to near zero levels for 1987 to 1994. Since 1994, abundance has shown a general upward trend, while at the same time exhibiting greater interannual variability. The second highest index value of 2.9 fish per tow occurred in 2006, before dropping back to just 0.2 fish per tow in 2007. (FIGURE)

Standard error is high and exhibits a similar trend as mean abundance. The CV is generally greater than 60%, and exceeds 90% in eight years. Because of the low catch rates and high variability, the TC has determined that this index provides little information on the abundance of weakfish. This is consistent with the NEFSC (2000) recommendation to use only indices from the core area.

TC Recommendation?? CV too high, get rid of it

### ZZ6.6 Rhode Island Trawl Survey

NEED DISCUSSION ON RI SURVEY

precision, geographical coverage, stock structure, and relative accuracy??

Keep it for now, but need precision estimates. RI currently converting to Access so it may be a few weeks. Brian will work on this.

### ZZ6.7 Connecticut DEP Long Island Sound Trawl Survey

Since 1984, the Connecticut DEP has conducted spring and fall trawl surveys in the Connecticut portion of Long Island Sound between the New York/Connecticut border in the west and New London, CT in the east. Survey effort consists of three spring cruises conducted during April, May and June, and three fall cruises in September and October. Stratified random sampling is employed based on four depth zones and three bottom types. Survey gear consists of a 14 x 9.1

m high-rise otter trawl with 0.196" codend mesh. The survey catches mostly YOY and age 1 weakfish as defined by examination of length frequencies. Indices of abundance for age 0 and age 1+ are developed as geometric mean catch per tow.

Sampling is limited to Long Island Sound. The Sound encompasses a very small portion of the weakfish range, but may serve as a primary spawning/nursery habitat in this region. Not a lot of spawning, but maybe eggs/juvs from other spawning areas come in

From 1984 to 1998, the YOY index varied without trend, and generally ranged from approximately 3 to 10 fish per tow, with relatively strong year classes (10-15 fish per tow) occurring in five years. In 1999, recruitment increased sharply and has remained above 30 fish per tow in all years except 2005 and 2006. Time series highs of more than 63 fish per tow occurred in 2000 and 2007, while minimum catches of approximately 1 fish or less occurred in 1984, 1986, and 2006. Coefficient of variation of the YOY index has exhibited a generally negative trend over the time series. (FIGURE)

The fall and spring age 1+ indices have never exceeded 1 fish per tow and 0.5 fish per tow, respectively. Except for the first few years of the time series, the two 1+ indices exhibit similar trends, and show strong positive correlation ($r = 0.55$). From 1984 to 1989, the fall index declines in abundance while the spring index remains stable or increases slightly. Both indices increase from 1989 to 1991, decrease through 1994, increase to time series highs in 1997 (fall) and 1999 (spring), and have generally declined since then. The CV for the fall index generally ranges from 0.2 to 0.6 and appears to have been on an increasing trend since 1997.

Low correlation was observed between the fall age 1+ index and the fall age 0 index lagged forward one year ($r = 0.06$; correlation table). Correlation was slightly better ($r = 0.2$) for the spring 1+ and fall age 0 lagged forward. One possible explanation is that weakfish in this area recruit to the spawning population at older ages; however, correlations between the 1+ indices and the age 0 index lagged forward two and three years were weaker, and in three of four cases, negative. This suggests that the Long Island Sound survey is inadequate for sampling either age 0 or age 1+ fish.

TC recommendation? Because this survey is conducted outside the apparent core area, NEFSC (2000) recommended that this survey not be used as an index of abundance. But large catches and good precision, so keep it.

### ZZ6.8 NYDEC Peconic Bay Juvenile Trawl Survey

The New York Division of Fish, Wildlife and Marine Resources has conducted a juvenile trawl survey in the Peconic Bay estuary of Long Island since1985. Weakfish was the primary target species when the survey was initiated, and Peconic Bay was selected for the survey area because of its importance as a weakfish spawning ground. Random sampling occurs weekly between May and October using a semi-balloon shrimp trawl with a 16 foot headrope and 0.5" stretch mesh codend liner. The survey samples mainly young of year weakfish, and a YOY index has historically been calculated as an arithmetic mean catch per tow over all sampling months. In 2005 and 2006, technical difficulties constrained sampling to May – July (2005) and July – October (2006), so a revised index using only July and August has been calculated. The two

indices show a similar increasing trend and are well correlated (r = 0.96). The July/August index provides higher estimates of abundance and appears to be more variable between years, although standard deviation as a ratio of the mean is lower for the July/August index than for all months combined. WHICH TO USE? – use July/August, need CIs but need more data to do it (now in log scale, need to calculate CIs?

The July/August index ranges from less than one fish per tow to more than 30/tow. Despite large interannual variations, there appears to be a gradual increase in recruitment over the time series. Strong year classes occurred in 1991, 1996, and 2005 (time series high). Standard error of the catch has increased over the time series as well; however, CV has decreased greatly from 1987 to 1996, and has remained below 1.5% since then. (FIGURE)

TC recommendation? Because this survey is conducted outside the apparent core area, NEFSC (2000) recommended that this survey not be used as an index of abundance. But good precision, so keep it.

### ZZ6.9 Delaware DFW Delaware Bay Juvenile Trawl Survey

In addition to their 30-foot trawl survey, the Delaware DFW conducts a fixed station survey in Delaware Bay targeting juvenile finfish. Sampling is conducted monthly from April through October using a semi-balloon otter trawl. The net has a 17' headrope and a 0.5" stretch mesh codend liner. Weakfish are a significant component of the catch, with the greatest majority of these weakfish (more than 99% in some years) being young of the year. A YOY index is calculated as the geometric mean number per tow during the June to October cruises.

As with the Delaware 30-foot index, the survey is restricted to Delaware Bay. Although this encompasses only a small portion of the geographic range of weakfish, the Bay is known to provide significant spawning and nursery habitat for the species.

Throughout this timeseries, recruitment indices have generally fallen between 5 and 15 fish per tow, with only 2 values below and three values above this range. Weak recruitment occurred in 1983 and 1988, with less than 5 fish per tow, while the two strongest recruitment events of 20.1 and 16.8 fish per tow occurred in 1991 and 2005, respectively. Average recruitment over the timeseries has been approximately 10.8 fish per tow. The index indicates three general stanzas in recruitment since 1981. From 1981 to 1990, recruitment was generally below the long term average. In 1991, recruitment increased to the timeseries high beginning a decade of above-average recruitment. In 2001, recruitment dropped below average and has remained there for five of the last seven years. (FIGURE)

Precision??

TC recommendation? Keep it

### ZZ6.10 Maryland DNR Chesapeake Bay and Coastal Bays Juvenile Trawl Surveys

The Maryland Department of Natural Resources conducts two juvenile trawl surveys: one in the Chesapeake Bay from 1980 to the present, and one in the coastal bays from 1972 to the present. Both surveys sample fixed stations using a 16 foot semi-balloon otter trawl with a 0.5" stretch

mesh codend liner. The coastal bays project samples monthly from April through October, while the Chesapeake survey runs monthly from May through October. Due to non-standardized survey methods during the early portions of both surveys, only data from 1989 onward are used to calculate YOY abundance indices. Indices are calculated as geometric mean catch per tow.

Both surveys are confined to Maryland state waters which constitute only a small portion of the weakfish range. Regardless, both survey areas are sheltered estuarine environments and may provide suitable spawning and nursery habitat for the species.

The Chesapeake index shows a steadily increasing trend from a timeseries low of 0.4 fish per tow in 1989 to the timeseries high of 8.1 fish per tow in 2001. Since 2001, the index has exhibited a steady decline to less than 2 fish per tow in 2007. The coastal bays index appears stable between 0.9 and 1.9 fish per tow for 1989 to 1994. In 1995, recruitment increases dramatically to 4.4 fish per tow, decreasing gradually back to 2.6 in 2001. During this period (1989 to 2001), interannual variability has been minor with few exceptions. Beginning in 2001, interannual variability increases dramatically. The weakest recruitment of the timeseries occurred in 2002, followed in 2003 by the timeseries high of 5.6 fish per tow. (FIGURE)

precision?? Get from Jim or Harry,

TC Recommendation?? Keep both but maybe down weight coastal bay index (if we weight the indices)

### ZZ6.11 Virginia Institute of Marine Science Chesapeake Bay Trawl Survey

The Virginia Institute of Marine Science (VIMS) has conducted a trawl survey in lower Chesapeake Bay since 1955. Over time there have been several changes to sampling strategy and survey area. Currently, sampling is conducted using a 30 foot semi-balloon otter trawl with a 6.35 mm codend liner. Sampling is performed monthly throughout the year using stratified random sampling in the mainstem bay and fixed stations in tributaries. Young of year are identified through examination of length frequencies (monthly ranges), and an index of recruitment is computed using August-October tows from three major tributaries.

The geographic region covered by the survey includes the Virginia portion of the Chesapeake Bay and lower portions of its three main tributaries (James, York, and Rappahannock Rivers). Although sampling does occur in the main stem, catches of weakfish are generally minimal in the Bay, so the index is limited to the three tributaries. Few large weakfish are present year round, but the estuaries provide suitable nursery grounds for juveniles.

Recruitment varies widely over the timeseries, ranging from less than 5 fish per tow to more than 35 fish per tow. Interannual variability is often large, particularly in the early portion of the timeseries, with the maximum and minimum indices occurring in consecutive years. From 1986 to 1990, the survey shows a rapid increase from 4.7 to 30.0 fish per tow, followed by a sharp drop back to 7.0 fish per tow by 1994. Recruitment rebounded slightly through 1999, but has exhibited a generally declining trend ever since. (FIGURE)

No estimates of survey variability are available for the current index. (Data were not provided, and the program has recently lost some key staff.) Geer (1994), however, indicates that between 1981 and 1993 several changes in gear, vessel, and station type occurred, the most recent between the 1990 and 1991 surveys. It is possible that some of the interannual variability observed in the index is due to these methodological changes.

TC recommendation - need more info – are data standardized re survey changes, is it geo mean, use river only or bay and river, use only stdized portion of time series

### ZZ6.12 North Carolina DMF Pamlico Sound Juvenile Trawl Survey

The North Carolina Division of Marine Fisheries conducts a juvenile trawl survey in Pamlico Sound. Sampling is conducted in June and September using a stratified random design. Survey gear consists of twin 30-foot mongoose trawl nets with 0.75" codend mesh. Data from these surveys are used to develop a 1+ index (June) and a YOY index (September), both based on length frequency analysis.

Between 1987 and 1999, the YOU index ranged from approximately 10 to 100 fish per tow, and was characterized by large interannual fluctuations. Strong year classes were present in 1988 and 1999, with weakest recruitment occurring in 1987 and 1993. From 1999 to 2002, recruitment dropped rapidly from 99.9 to 22 fish per tow. Since 2002, the index indicates a modest rebound to 56.8 fish per tow in 2007 and exhibits much less interannual variability.

For the early portion of the time series, the 1+ index shows little correlation with the YOY index. Around the mid 1990s, correlation between the indices improves until the last two years. The time series high occurred in 2000 (consistent with the strong 1999 year class), with the second highest value occurring in 2006. Low values were observed in 1989 to 1992, 2003, and 2007.

precision, geographical coverage

TC Recommendation?? – get geo mean from Lee, rewrite discussion

### ZZ6.13 Pamlico Sound Independent Gillnet Study (PSIGNS)

This is the first weakfish stock assessment to evaluate the PSIGNS survey. Sampling in Pamlico Sound was initiated in May of 2001 and has sampled continuously since that time. The major objective of the PSIGNS is to provide independent relative abundance indices for key estuarine species.

Sampling uses a stratified random design based on area and water depth. Twice per month a deep-water and shallow-water sample are collected from each of 8 areas using a gillnet consisting of eight 30 yard segments of 3, 3½, 4, 4½, 5, 5½, 6, 6½ inch stretched mesh gill net. Nets are typically deployed within an hour of sunset and retrieved the next morning, for approximate soak times of 12 h. This sampling design results in a total of approximately 32 gill net samples (16 deep and 16 shallow samples) being collected per month across both the Rivers and Sound. Catch rates of target species were calculated annually and expressed as an overall CPUE along with corresponding length class distributions. The overall CPUE provides a relative

index of abundance showing availability of each species to the study, while the length distribution and age CPUE estimates show the size structure of each species for a given year. The overall CPUE was defined as the number of a species of fish captured per sample and was further expressed as the number of a species of fish at length per sample, with a sample being one array of nets fished for 12 hours. Due to disproportionate sizes of each stratum and region, the final CPUE estimate was weighted. For weakfish the CPUE at age was calculated for 6-month periods (Jan-Jun and Jul-Dec) in the same manner as was done for the CAA workup in the last assessment.

ADD NEAMAP and ChesMMAP – not for index, but use bio data

**ZZ6.14 MRFSS**

Historically, a fishery dependent index of weakfish abundance was developed using recreational catch per "directed trip" (trips where weakfish was identified as a target species; *cf.* NEFSC 1998, 2000). During the review of the 2000 assessment, the SARC expressed concern regarding fishery dependent indices. Potential sources of bias in fishery dependent indices include non-random distribution of effort, and hyperstability of the index (as abundance - and therefore catch – declines, so does the number of trips; Hilborn and Walters 1992).

In 2006, a revised recreational index was developed that the Technical Committee feels largely circumvents the concerns expressed by the 30$^{th}$ SAW. Estimates of catch used are all fish (A+B1+B2) captured by the recreational private/rental boat mode in state waters of the mid-Atlantic region (New York to Virginia). As described in Crecco (2005), the private/rental mode is highly mobile and capable of catching weakfish over a large range of sizes. Catches were constrained to the mid-Atlantic region because private/rental boat catches from this region have accounted for greater than 60% of annual catch. Two estimates of effort were used to convert catch to CPUE. The first, as described in Crecco (2005) uses all private/rental boat trips in state waters of the mid-Atlantic region. The second, detailed by Brust (2004) estimates effort as the number of private/rental boat trips in mid-Atlantic state waters that captured any of a suite of species typically associated with catches of weakfish. The two indices are highly correlated (FIGURE). Although the 2006 assessment used the index based on the suite of associated species, the current assessment uses the index based on all mid-Atlantic private/rental boat trips. This index is preferable because of its ease of calculation without loss of information, and because it provides consistency between assessment methodologies (*i.e.* VPA vs. relative F). (FIGURE)

The methods described above include both harvested and discarded fish. Based on assumptions regarding availability to the fishery (gear and area) at size, this method is considered to provide a composite index of ages 2+. A second index was developed using similar methods, but including only harvested fish. Recreational length frequency data from the northern region, early/late season were used to expand the number harvested to harvest at size. The northern early/late age-length key was then used to partition harvest into ages. This method provides indices at age for 3 through 6+.

Both indices are developed using data from mid-Atlantic state waters. This region encompasses the primary distribution of weakfish within its range. Although all sizes and ages of weakfish

are present in this region, younger fish are not considered to be captured or harvested by the fishery, so the indices are only representative of mature fish.

DISCUSS INDICES (Need to develop - 06 assess used assoc spp trips; want to change to all trips)

Estimates of precision are available for the different components of the indices (catch, harvest, and effort); however, there are no direct estimates of survey precision. Discussions on uncertainty in catch and effort estimates are presented in section ZZ5.2.

TC Recommendation??

Jim's work – favors aggregate biomass assessment; looking at alternative methods to analyze indices; trying to ID criteria for good vs bad index; did work on biomass indices, not numerical indices; criteria are precision, accuracy (hard to determine), consistency (low interannual variability) and coherence with other surveys – could use these for indices presented above; NEFSC can't be salvaged; NJ index not weighted by stratum size; 3 possible "usable" NJ biomass indices – "best" is positive tows * mn wt / tow; can use NJ pos tows index as tuning index, can even use aged

Lee's work – include as aged index; Lee to work on write up

Yan – standardized CPUEs – recommends using stdized surveys; right now not all indices are stdized (she hasn't received all data), also none of them have been aged; right now, keep our data, but if in future (even during this assessment) find Yan's data is better, we can reconsider

Joseph – natural mortality – review different non-age based and several age-specific M methods; all have drawbacks; many sensitive to reference value; choice of method is subjective, but leaning towards lorenzen cuz population specific;

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**Table ZZ4.6-1. Commercial landings and (percent of annual total) by state and year. Landings are in metric tons.**

| | MA | RI | CT | NY | NJ | DE | MD | VA | NC | SC | GA | FL | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1981 | 18.1 | 109.8 | 12.4 | 615.9 | 1,701.1 | 477.0 | 153.5 | 1,121.2 | 7,662.9 | 0.0 | 0.2 | 86.3 | 11,958.4 |
| | (0.15) | (0.92) | (0.1) | (5.15) | (14.23) | (3.99) | (1.28) | (9.38) | (64.08) | (0) | (0) | (0.72) | |
| 1982 | 10.4 | 80.2 | 11.6 | 570.2 | 940.5 | 587.2 | 113.0 | 974.9 | 5,466.9 | 0.2 | 0.3 | 79.9 | 8,835.3 |
| | (0.12) | (0.91) | (0.13) | (6.45) | (10.64) | (6.65) | (1.28) | (11.03) | (61.88) | (0) | (0) | (0.9) | |
| 1983 | 3.1 | 74.3 | 19.4 | 385.6 | 985.5 | 409.1 | 176.9 | 1,176.1 | 4,642.0 | 0.0 | 1.2 | 53.4 | 7,926.6 |
| | (0.04) | (0.94) | (0.24) | (4.86) | (12.43) | (5.16) | (2.23) | (14.84) | (58.56) | (0) | (0.02) | (0.67) | |
| 1984 | 2.2 | 76.0 | 14.2 | 219.8 | 1,248.1 | 354.9 | 147.4 | 956.6 | 5,892.6 | 0.0 | 0.4 | 57.1 | 8,969.3 |
| | (0.02) | (0.85) | (0.16) | (2.45) | (13.92) | (3.96) | (1.64) | (10.67) | (65.7) | (0) | (0) | (0.64) | |
| 1985 | 1.4 | 74.0 | 12.8 | 175.2 | 1,374.4 | 449.4 | 143.4 | 944.5 | 4,454.9 | 0.0 | 0.0 | 60.0 | 7,690.0 |
| | (0.02) | (0.96) | (0.17) | (2.28) | (17.87) | (5.84) | (1.86) | (12.28) | (57.93) | (0) | (0) | (0.78) | |
| 1986 | 2.6 | 57.9 | 6.2 | 163.2 | 1,455.4 | 328.2 | 152.7 | 904.5 | 6,490.7 | 0.0 | 0.0 | 49.3 | 9,610.7 |
| | (0.03) | (0.6) | (0.06) | (1.7) | (15.14) | (3.41) | (1.59) | (9.41) | (67.54) | (0) | (0) | (0.51) | |
| 1987 | 0.8 | 35.7 | 13.4 | 149.3 | 949.9 | 262.1 | 166.4 | 890.3 | 5,220.2 | 0.0 | 0.1 | 55.8 | 7,744.0 |
| | (0.01) | (0.46) | (0.17) | (1.93) | (12.27) | (3.38) | (2.15) | (11.5) | (67.41) | (0) | (0) | (0.72) | |
| 1988 | 1.7 | 8.8 | 1.1 | 56.5 | 1,058.2 | 240.7 | 377.7 | 668.2 | 6,845.6 | 0.0 | 0.0 | 52.2 | 9,310.7 |
| | (0.02) | (0.09) | (0.01) | (0.61) | (11.37) | (2.59) | (4.06) | (7.18) | (73.52) | (0) | (0) | (0.56) | |
| 1989 | 0.9 | 4.4 | 1.0 | 46.9 | 661.6 | 240.5 | 337.4 | 465.0 | 4,588.5 | 0.1 | 0.0 | 78.1 | 6,424.4 |
| | (0.01) | (0.07) | (0.02) | (0.73) | (10.3) | (3.74) | (5.25) | (7.24) | (71.42) | (0) | (0) | (1.22) | |
| 1990 | 0.8 | 11.2 | 0.6 | 9.0 | 439.2 | 278.1 | 300.4 | 547.7 | 2,631.8 | 0.0 | 0.0 | 62.2 | 4,281.0 |
| | (0.02) | (0.26) | (0.01) | (0.21) | (10.26) | (6.5) | (7.02) | (12.79) | (61.48) | (0) | (0) | (1.45) | |
| 1991 | 0.9 | 11.3 | 9.7 | 50.6 | 532.6 | 225.6 | 148.9 | 480.7 | 2,408.0 | 0.0 | 0.0 | 74.8 | 3,943.1 |
| | (0.02) | (0.29) | (0.25) | (1.28) | (13.51) | (5.72) | (3.78) | (12.19) | (61.07) | (0) | (0) | (1.9) | |
| 1992 | 1.4 | 13.7 | 1.6 | 76.2 | 426.7 | 164.4 | 174.8 | 249.5 | 2,205.6 | 0.0 | 0.0 | 67.1 | 3,381.0 |
| | (0.04) | (0.41) | (0.05) | (2.25) | (12.62) | (4.86) | (5.17) | (7.38) | (65.24) | (0) | (0) | (1.98) | |
| 1993 | 0.5 | 4.5 | 0.7 | 40.1 | 378.5 | 88.3 | 82.5 | 493.5 | 1,954.7 | 0.0 | 0.0 | 65.5 | 3,108.8 |
| | (0.02) | (0.14) | (0.02) | (1.29) | (12.18) | (2.84) | (2.65) | (15.87) | (62.88) | (0) | (0) | (2.11) | |
| 1994 | 0.0 | 8.2 | 5.0 | 45.1 | 315.4 | 118.8 | 63.9 | 587.1 | 1,583.0 | 0.0 | 0.0 | 81.5 | 2,808.0 |
| | (0) | (0.29) | (0.18) | (1.61) | (11.23) | (4.23) | (2.28) | (20.91) | (56.37) | (0) | (0) | (2.9) | |
| 1995 | 0.2 | 23.9 | 2.9 | 78.2 | 393.4 | 127.6 | 31.5 | 673.6 | 1,865.8 | 0.0 | 0.0 | 22.8 | 3,219.9 |
| | (0.01) | (0.74) | (0.09) | (2.43) | (12.22) | (3.96) | (0.98) | (20.92) | (57.95) | (0) | (0) | (0.71) | |
| 1996 | 0.0 | 19.7 | 3.1 | 165.7 | 372.9 | 0.0 | 60.2 | 719.9 | 1,804.3 | 0.0 | 0.0 | 2.0 | 3,147.8 |
| | (0) | (0.63) | (0.1) | (5.26) | (11.85) | (0) | (1.91) | (22.87) | (57.32) | (0) | (0) | (0.06) | |
| 1997 | 0.0 | 14.1 | 5.0 | 152.7 | 470.1 | 253.5 | 87.4 | 706.7 | 1,615.3 | 0.0 | 0.0 | 5.3 | 3,310.1 |
| | (0) | (0.43) | (0.15) | (4.61) | (14.2) | (7.66) | (2.64) | (21.35) | (48.8) | (0) | (0) | (0.16) | |
| 1998 | 0.2 | 35.0 | 6.6 | 225.2 | 818.6 | 250.7 | 110.9 | 845.5 | 1,521.4 | 0.0 | 0.0 | 6.8 | 3,820.9 |
| | (0.01) | (0.92) | (0.17) | (5.89) | (21.42) | (6.56) | (2.9) | (22.13) | (39.82) | (0) | (0) | (0.18) | |
| 1999 | 1.2 | 57.3 | 10.1 | 222.2 | 585.7 | 199.7 | 101.4 | 759.3 | 1,187.3 | 0.0 | 0.0 | 7.9 | 3,132.1 |
| | (0.04) | (1.83) | (0.32) | (7.09) | (18.7) | (6.38) | (3.24) | (24.24) | (37.91) | (0) | (0) | (0.25) | |

**Table 1 (continued). Commercial landings and (percent of annual total) by state and year. Landings are in metric tons.**

| | MA | RI | CT | NY | NJ | DE | MD | VA | NC | SC | GA | FL | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2000 | 0.2 | 85.9 | 3.6 | 160.0 | 486.0 | 149.1 | 94.5 | 618.2 | 847.8 | 0.0 | 0.0 | 4.3 | 2,449.6 |
| | (0.01) | (3.51) | (0.15) | (6.53) | (19.84) | (6.09) | (3.86) | (25.24) | (34.61) | (0) | (0) | (0.18) | |
| 2001 | 0.1 | 49.7 | 3.1 | 262.5 | 379.9 | 85.1 | 84.3 | 508.9 | 889.2 | 0.0 | 0.0 | 4.9 | 2,267.7 |
| | (0) | (2.19) | (0.14) | (11.58) | (16.75) | (3.75) | (3.72) | (22.44) | (39.21) | (0) | (0) | (0.22) | |
| 2002 | 0.4 | 55.7 | 4.6 | 233.1 | 391.5 | 78.4 | 50.5 | 518.9 | 829.3 | 0.0 | 0.0 | 2.6 | 2,165.0 |
| | (0.02) | (2.57) | (0.21) | (10.77) | (18.08) | (3.62) | (2.33) | (23.97) | (38.3) | (0) | (0) | (0.12) | |
| 2003 | 0.2 | 28.7 | 1.4 | 65.5 | 154.3 | 41.5 | 21.5 | 208.4 | 385.0 | 0.0 | 0.0 | 1.2 | 907.7 |
| | (0.02) | (3.16) | (0.15) | (7.22) | (17) | (4.57) | (2.37) | (22.96) | (42.41) | (0) | (0) | (0.13) | |
| 2004 | 0.0 | 17.4 | 2.8 | 80.9 | 92.8 | 23.3 | 0.0 | 161.9 | 310.9 | 0.0 | 0.0 | 1.2 | 691.2 |
| | (0) | (2.52) | (0.41) | (11.7) | (13.43) | (3.37) | (0) | (23.42) | (44.98) | (0) | (0) | (0.17) | |
| 2005 | 0.0 | 18.9 | 2.8 | 49.8 | 29.2 | 32.1 | 16.2 | 176.9 | 191.2 | 0.0 | 0.0 | 3.3 | 520.4 |
| | (0) | (3.63) | (0.54) | (9.57) | (5.61) | (6.17) | (3.11) | (33.99) | (36.74) | (0) | (0) | (0.63) | |
| 2006 | 3.9 | 20.2 | 3.2 | 69.3 | 93.7 | 15.6 | 23.2 | 85.2 | 164.6 | 0.0 | 0.0 | 2.7 | 481.6 |
| | (0.81) | (4.19) | (0.66) | (14.39) | (19.46) | (3.24) | (4.82) | (17.69) | (34.18) | (0) | (0) | (0.56) | |
| 2007 | 0.2 | 9.3 | 0.9 | 39.3 | 74.6 | 11.1 | 12.6 | 156.7 | 79.6 | 0.0 | 0.0 | 3.5 | 387.9 |
| | (0.04) | (2.41) | (0.22) | (10.13) | (19.23) | (2.87) | (3.26) | (40.39) | (20.53) | (0) | (0) | (0.91) | |

**Table ZZ4.6-2. Recreational harvest and (percent of annual total) by state and year. Harvest values are numbers of fish.**

| Year | MA | RI | CT | NY | NJ | DE | MD | VA | NC | SC | GA | FL | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1981 | 5,946 | 18,371 | 18,707 | 275,120 | 1,028,787 | 122,744 | 177,761 | 7,484,780 | 204,230 | 2,580 | 2,433 | | 9,344,461 |
| | (0.06) | (0.2) | (0.2) | (2.94) | (11.01) | (1.31) | (1.9) | (80.1) | (2.19) | (0.03) | (0.03) | (0) | |
| 1982 | | 18,614 | 11,769 | 88,234 | 104,066 | 217,821 | 440,146 | 715,892 | 200,045 | 17,342 | | 40,161 | 1,854,090 |
| | (0) | (1) | (0.63) | (4.76) | (5.61) | (11.75) | (23.74) | (38.61) | (10.79) | (0.94) | (0) | (2.17) | |
| 1983 | 2,732 | 74,608 | 6,363 | 36,934 | 2,857,093 | 1,009,899 | 595,286 | 354,846 | 387,871 | 6,807 | 17,209 | 293,303 | 5,642,951 |
| | (0.05) | (1.32) | (0.11) | (0.65) | (50.63) | (17.9) | (10.55) | (6.29) | (6.87) | (0.12) | (0.3) | (5.2) | |
| 1984 | 2,237 | 0 | 1,561 | 20,133 | 1,026,043 | 593,107 | 104,057 | 782,848 | 489,468 | 7,836 | | 493,521 | 3,520,811 |
| | (0.06) | (0) | (0.04) | (0.57) | (29.14) | (16.85) | (2.96) | (22.23) | (13.9) | (0.22) | (0) | (14.02) | |
| 1985 | | 17,092 | 2,874 | 89,538 | 812,839 | 365,693 | 305,799 | 505,223 | 217,671 | 61,788 | 4,811 | 36,340 | 2,419,668 |
| | (0) | (0.71) | (0.12) | (3.7) | (33.59) | (15.11) | (12.64) | (20.88) | (9) | (2.55) | (0.2) | (1.5) | |
| 1986 | | 4,595 | 7,315 | 34,582 | 2,500,622 | 914,489 | 1,947,394 | 2,418,046 | 611,363 | 78,315 | 18,130 | 129,270 | 8,664,121 |
| | (0) | (0.05) | (0.08) | (0.4) | (28.86) | (10.55) | (22.48) | (27.91) | (7.06) | (0.9) | (0.21) | (1.49) | |
| 1987 | | | 777 | 7,447 | 1,666,619 | 638,342 | 824,883 | 1,015,413 | 624,160 | 18,841 | 10,802 | 64,248 | 4,871,532 |
| | (0) | (0) | (0.02) | (0.15) | (34.21) | (13.1) | (16.93) | (20.84) | (12.81) | (0.39) | (0.22) | (1.32) | |
| 1988 | | | 0 | 13,215 | 642,032 | 974,712 | 1,163,766 | 2,297,053 | 438,148 | 1,834 | 0 | 95,509 | 5,626,269 |
| | (0) | (0) | (0) | (0.23) | (11.41) | (17.32) | (20.68) | (40.83) | (7.79) | (0.03) | (0) | (1.7) | |
| 1989 | | | | 6,436 | 303,289 | 254,170 | 226,505 | 357,864 | 190,193 | 6,810 | 8,245 | 141,880 | 1,495,392 |
| | (0) | (0) | (0) | (0.43) | (20.28) | (17) | (15.15) | (23.93) | (12.72) | (0.46) | (0.55) | (9.49) | |
| 1990 | | 407 | | 3,057 | 216,385 | 179,837 | 370,528 | 286,458 | 91,300 | 8,027 | 2,273 | 73,983 | 1,232,255 |
| | (0) | (0.03) | (0) | (0.25) | (17.56) | (14.59) | (30.07) | (23.25) | (7.41) | (0.65) | (0.18) | (6) | |
| 1991 | | | 18,695 | 28,072 | 545,665 | 366,464 | 221,242 | 351,947 | 140,826 | 19,616 | 4,954 | 115,210 | 1,812,691 |
| | (0) | (0) | (1.03) | (1.55) | (30.1) | (20.22) | (12.21) | (19.42) | (7.77) | (1.08) | (0.27) | (6.36) | |
| 1992 | | 9,624 | 434 | 5,282 | 311,659 | 100,561 | 137,260 | 265,645 | 35,490 | 23,501 | 1,751 | 68,943 | 960,150 |
| | (0) | (1) | (0.05) | (0.55) | (32.46) | (10.47) | (14.3) | (27.67) | (3.7) | (2.45) | (0.18) | (7.18) | |
| 1993 | | | 2,460 | 12,610 | 203,915 | 235,312 | 238,768 | 108,392 | 106,737 | 7,360 | 14,752 | 148,968 | 1,079,274 |
| | (0) | (0) | (0.23) | (1.17) | (18.89) | (21.8) | (22.12) | (10.04) | (9.89) | (0.68) | (1.37) | (13.8) | |
| 1994 | | | 0 | 1,872 | 591,571 | 300,211 | 332,846 | 169,740 | 177,965 | 46,858 | 718 | 204,714 | 1,826,495 |
| | (0) | (0) | (0) | (0.1) | (32.39) | (16.44) | (18.22) | (9.29) | (9.74) | (2.57) | (0.04) | (11.21) | |
| 1995 | | 1,568 | | 22,310 | 671,850 | 406,730 | 88,695 | 226,682 | 62,475 | 29,897 | 22,437 | 55,435 | 1,588,079 |
| | (0) | (0.1) | (0) | (1.4) | (42.31) | (25.61) | (5.59) | (14.27) | (3.93) | (1.88) | (1.41) | (3.49) | |
| 1996 | | 0 | | 16,320 | 1,104,251 | 633,920 | 183,408 | 193,861 | 90,704 | 5,695 | 5,413 | 35,757 | 2,269,329 |
| | (0) | (0) | (0) | (0.72) | (48.66) | (27.93) | (8.08) | (8.54) | (4) | (0.25) | (0.24) | (1.58) | |
| 1997 | | 1,415 | 517 | 112,986 | 1,028,334 | 647,529 | 162,900 | 557,809 | 184,954 | 2,039 | 44,202 | 72,970 | 2,815,655 |
| | (0) | (0.05) | (0.02) | (4.01) | (36.52) | (23) | (5.79) | (19.81) | (6.57) | (0.07) | (1.57) | (2.59) | |
| 1998 | 618 | 0 | 2,183 | 21,392 | 920,558 | 455,603 | 290,051 | 463,525 | 191,181 | 15,838 | 718 | 24,678 | 2,386,345 |
| | (0.03) | (0) | (0.09) | (0.9) | (38.58) | (19.09) | (12.15) | (19.42) | (8.01) | (0.66) | (0.03) | (1.03) | |
| 1999 | | 2,296 | 1,606 | 18,347 | 583,883 | 224,307 | 340,096 | 229,209 | 127,163 | 3,941 | 1,679 | 119,027 | 1,651,554 |
| | (0) | (0.14) | (0.1) | (1.11) | (35.35) | (13.58) | (20.59) | (13.88) | (7.7) | (0.24) | (0.1) | (7.21) | |

**Table ZZ4.6-2 (continued). Recreational harvest and (percent of annual total) by state and year. Harvest values are numbers of fish.**

| | MA | RI | CT | NY | NJ | DE | MD | VA | NC | SC | GA | FL | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2000 | | 712 | 7,342 | 42,406 | 760,279 | 311,553 | 475,348 | 286,752 | 71,247 | 5,585 | 4,181 | 123,797 | 2,089,202 |
| | (0) | (0.03) | (0.35) | (2.03) | (36.39) | (14.91) | (22.75) | (13.73) | (3.41) | (0.27) | (0.2) | (5.93) | |
| 2001 | | 2,301 | 715 | 28,126 | 736,069 | 72,451 | 302,719 | 175,872 | 158,605 | | 3,316 | 46,409 | 1,526,583 |
| | (0) | (0.15) | (0.05) | (1.84) | (48.22) | (4.75) | (19.83) | (11.52) | (10.39) | (0) | (0.22) | (3.04) | |
| 2002 | | 1,420 | 1,796 | 24,962 | 492,876 | 121,884 | 100,467 | 178,110 | 90,170 | 90,245 | 852 | 69,106 | 1,171,888 |
| | (0) | (0.12) | (0.15) | (2.13) | (42.06) | (10.4) | (8.57) | (15.2) | (7.69) | (7.7) | (0.07) | (5.9) | |
| 2003 | 109 | 298 | 443 | 9,234 | 151,101 | 20,124 | 41,048 | 86,112 | 153,753 | 4,162 | 1,573 | 29,614 | 497,571 |
| | (0.02) | (0.06) | (0.09) | (1.86) | (30.37) | (4.04) | (8.25) | (17.31) | (30.9) | (0.84) | (0.32) | (5.95) | |
| 2004 | | 0 | 0 | 7,596 | 183,649 | 6,967 | 29,645 | 103,181 | 237,395 | 153,589 | 9,815 | 46,020 | 777,857 |
| | (0) | (0) | (0) | (0.98) | (23.61) | (0.9) | (3.81) | (13.26) | (30.52) | (19.75) | (1.26) | (5.92) | |
| 2005 | | 1,009 | | 359 | 1,053,005 | 19,031 | 22,164 | 30,346 | 163,265 | 129,575 | 5,764 | 79,021 | 1,503,539 |
| | (0) | (0.07) | (0) | (0.02) | (70.04) | (1.27) | (1.47) | (2.02) | (10.86) | (8.62) | (0.38) | (5.26) | |
| 2006 | | 3,297 | | 9,123 | 417,527 | 11,158 | 470 | 58,814 | 153,696 | 7,123 | 3,501 | 80,427 | 745,136 |
| | (0) | (0.44) | (0) | (1.22) | (56.03) | (1.5) | (0.06) | (7.89) | (20.63) | (0.96) | (0.47) | (10.79) | |
| 2007 | | 0 | | 7,120 | 209,310 | 4,182 | 10,316 | 44,493 | 114,332 | 71,230 | 4,712 | 118,743 | 584,438 |
| | (0) | (0) | (0) | (1.22) | (35.81) | (0.72) | (1.77) | (7.61) | (19.56) | (12.19) | (0.81) | (20.32) | |

**Table ZZ5.1-1.** Sample size and parameter estimates for weakfish length-weight equations.

| Region | Year | Season | N | a | b |
|---|---|---|---|---|---|
| North | 2004 | Early | 1487 | 1.85E-08 | 3.023663 |
| North | 2004 | Late | 2997 | 3.2E-08 | 2.927907 |
| North | 2005 | Early | 878 | 4.25E-08 | 2.884075 |
| North | 2005 | Late | 2724 | 4.2E-08 | 2.892038 |
| North | 2006 | Early | 1135 | 2.95E-08 | 2.956832 |
| North | 2006 | Late | 2028 | 1.13E-07 | 2.735412 |
| South | 2004 | Early | 322 | 5.34E-08 | 2.867107 |
| South | 2004 | Late | 280 | 6.78E-08 | 2.820563 |
| South | 2005 | Early | 295 | 2.5E-08 | 2.979039 |
| South | 2005 | Late | 289 | 2.11E-08 | 3.009672 |
| South | 2006 | Early | 367 | 1.68E-08 | 3.045197 |
| South | 2006 | Late | 278 | 5.7E-08 | 2.843432 |

**Table ZZ5.1-2.** Biological sampling intensity by state and season for recent years (need to update 2007).

| | | | Commercial | | | | Recreational | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Season** | **State** | **Ages** | **Lengths** | **Landings (MT)** | **Lengths / MT** | **Lengths** | **Landings (MT)** | **Lengths / MT** |
| 2001 | Early | MA | 0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| | | RI | 178** | 178** | 10.8 | 16.5 | 0 | 0.0 | 0.0 |
| | | CT | 34 | 0 | 0.3 | 0.0 | 0 | 0.0 | 0.0 |
| | | NY | 0 | 0 | 39.9 | 0.0 | 9 | 39.0 | 0.2 |
| | | NJ | 0 | 0 | 108.0 | 0.0 | 43 | 114.8 | 0.4 |
| | | DE | 300 | 370 | 75.0 | 4.9 | 69 | 50.7 | 1.4 |
| | | MD | 0 | 8 | 27.3 | 0.3 | 5 | 15.6 | 0.3 |
| | | VA | 152 | 758 | 249.9 | 3.0 | 82 | 107.6 | 0.8 |
| | | NC | 328 | 9,747 | 723.3 | 13.5 | 19 | 2.4 | 7.8 |
| | | SC | | | | 0.0 | 0 | 0.0 | 0.0 |
| | | GA | | | 0.0 | 0.0 | 1 | 0.1 | 8.3 |
| | | FL | | 0 | 2.4 | 0.0 | 6 | 10.4 | 0.6 |
| | | SEAMAP | 99 | | | | | | |
| | | **Total** | **992** | **11,306** | **1,236.9** | **9.1** | **234** | **340.8** | **0.7** |
| 2001 | Late | MA | 0 | 0 | 0.1 | 0.0 | 0 | 0.0 | 0.0 |
| | | RI | 178** | 178** | 38.9 | 4.6 | 0 | 0.0 | 0.0 |
| | | CT | 69 | 0 | 2.7 | 0.0 | 1 | 2.2 | 0.5 |
| | | NY | 0 | 372** | 222.9 | 1.7 | 3 | 29.7 | 0.1 |
| | | NJ | 0 | 0 | 271.8 | 0.0 | 362 | 452.7 | 0.8 |
| | | DE | 861 | 0 | 2.7 | 0.0 | 59 | 27.8 | 2.1 |
| | | MD | 193 | 261 | 68.2 | 3.8 | 294 | 241.9 | 1.2 |
| | | VA | 420 | 1,806 | 280.6 | 6.4 | 106 | 61.7 | 1.7 |
| | | NC | 220 | 3,199 | 158.8 | 20.1 | 161 | 69.4 | 2.3 |
| | | SC | | | | 0.0 | 0 | 0.0 | 0.0 |
| | | GA | | | | 0.0 | 2 | 1.2 | 1.6 |
| | | FL | | 0 | 2.5 | 0.0 | 17 | 7.6 | 2.2 |
| | | SEAMAP | 151 | | | | | | |
| | | NEFSC | 617 | | | | | | |
| | | **Total** | **2,699** | **6,003** | **1,049.2** | **5.7** | **1005** | **894.2** | **1.1** |
| 2002 | Early | MA | 0 | 0 | 0.2 | 0.0 | 0 | 0.0 | 0.0 |
| | | RI | 50 | 50 | 30.4 | 1.6 | 0 | 0.0 | 0.0 |
| | | CT | 22 | 0 | 2.6 | 0.0 | 0 | 0.0 | 0.0 |
| | | NY | 0 | 0 | 45.0 | 0.0 | 4 | 9.5 | 0.4 |
| | | NJ | 0 | 0 | 92.4 | 0.0 | 101 | 229.0 | 0.4 |
| | | DE | 561 | 1,179 | 54.9 | 21.5 | 201 | 81.1 | 2.5 |
| | | MD | 20 | 21 | 11.0 | 1.9 | 12 | 10.8 | 1.1 |
| | | VA | 328 | 2,399 | 325.8 | 7.4 | 110 | 39.9 | 2.8 |
| | | NC | 231 | 9,121 | 691.8 | 13.2 | 47 | 7.9 | 5.9 |
| | | SC | 0 | | | 0.0 | 0 | 0.2 | 0.0 |
| | | GA | 0 | | | 0.0 | 0 | 0.0 | 0.0 |
| | | FL | 0 | 0 | 1.6 | 0.0 | 17 | 21.2 | 0.8 |
| | | SEAMAP | 122* | | | 0.0 | | | 0.0 |
| | | CHESMAP | 141 | | | 0.0 | | | 0.0 |
| | | **Total** | **1,478** | **12,770** | **1,255.7** | **10.2** | **492** | **399.5** | **1.2** |

**Table ZZ5.1-2 (continued).** Biological sampling intensity by state and season for recent years.

| | | | Commercial | | | | Recreational | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Season** | **State** | **Ages** | **Lengths** | **Landings (MT)** | **Lengths / MT** | **Lengths** | **Landings (MT)** | **Lengths / MT** |
| 2002 | Late | MA | 0 | 0 | 0.2 | 0.0 | 0 | 0.0 | 0.0 |
| | | RI | 0 | 0 | 25.2 | 0.0 | 2 | 1.7 | 1.2 |
| | | CT | 42 | 0 | 2.0 | 0.0 | 1 | 5.1 | 0.2 |
| | | NY | 0 | 0 | 188.1 | 0.0 | 8 | 17.1 | 0.5 |
| | | NJ | 0 | 0 | 299.0 | 0.0 | 164 | 321.7 | 0.5 |
| | | DE | 760 | 0 | 23.5 | 0.0 | 58 | 29.2 | 2.0 |
| | | MD | 44 | 216 | 44.8 | 4.8 | 58 | 68.2 | 0.9 |
| | | VA | 318 | 4,170 | 211.2 | 19.7 | 141 | 94.1 | 1.5 |
| | | NC | 281 | 3,642 | 130.8 | 27.8 | 59 | 29.6 | 2.0 |
| | | SC | | | | 0.0 | 7 | 22.6 | 0.3 |
| | | GA | | | | 0.0 | 1 | 0.3 | 3.2 |
| | | FL | | 0 | 1.1 | 0.0 | 21 | 5.7 | 3.7 |
| | | SEAMAP | 153 | | | 0.0 | | | 0.0 |
| | | CHESMAP | 550 | | | 0.0 | | | 0.0 |
| | | NEFSC | 692 | | | 0.0 | | | 0.0 |
| | | **Total** | **2,838** | **8,028** | **925.9** | **8.7** | **520** | **595.2** | **0.9** |
| 2003 | Early | MA | 0 | 0 | 0.2 | 0.0 | 0 | 0.0 | 0.0 |
| | | RI | 0 | 0 | 8.4 | 0.0 | 0 | 0.0 | 0.0 |
| | | CT | 4 | 0 | 4.6 | 0.0 | 0 | 0.0 | 0.0 |
| | | NY | 0 | 0 | 30.6 | 0.0 | 1 | 11.6 | 0.1 |
| | | NJ | 36 | 104 | 70.4 | 1.5 | 22 | 58.2 | 0.4 |
| | | DE | 580 | 944 | 38.4 | 24.6 | 14 | 4.8 | 2.9 |
| | | MD | 0 | 7 | 3.2 | 2.2 | 0 | 0.0 | 0.0 |
| | | VA | 350 | 1,900 | 100.5 | 18.9 | 41 | 49.8 | 0.8 |
| | | NC | 269 | 5,227 | 267.9 | 19.5 | 42 | 15.6 | 2.7 |
| | | SC | | | | 0.0 | 0 | 0.0 | 0.0 |
| | | GA | | | | 0.0 | 0 | 0.0 | 0.0 |
| | | FL | | 0 | 1.0 | 0.0 | 9 | 4.5 | 2.0 |
| | | SEAMAP | 219* | | | 0.0 | | | 0.0 |
| | | CHESMAP | 78 | | | 0.0 | | | 0.0 |
| | | **Total** | **1,500** | **8,182** | **525.2** | **15.6** | **129** | **144.5** | **0.9** |
| 2003 | Late | MA | 0 | 0 | 0.0 | 0.0 | 1 | 0.4 | 2.5 |
| | | RI | 211 | 343 | 20.3 | 16.9 | 1 | 1.1 | 0.9 |
| | | CT | 22 | 0 | 0.3 | 0.0 | 1 | 1.6 | 0.6 |
| | | NY | 0 | 0 | 34.7 | 0.0 | 4 | 5.3 | 0.8 |
| | | NJ | 29 | 0 | 83.6 | 0.0 | 38 | 93.2 | 0.4 |
| | | DE | 372 | 0 | 3.1 | 0.0 | 23 | 21.5 | 1.1 |
| | | MD | 202 | 276 | 11.1 | 24.9 | 17 | 11.2 | 1.5 |
| | | VA | 323 | 2,226 | 108.1 | 20.6 | 49 | 47.9 | 1.0 |
| | | NC | 220 | 3,523 | 114.1 | 30.9 | 89 | 57.6 | 1.5 |
| | | SC | | | | 0.0 | 2 | 2.0 | 1.0 |
| | | GA | | | | 0.0 | 3 | 0.6 | 5.0 |
| | | FL | | 0 | 0.2 | 0.0 | 13 | 5.6 | 2.3 |
| | | SEAMAP | 0 | | | 0.0 | | | 0.0 |
| | | CHESMAP | 595* | | | 0.0 | | | 0.0 |
| | | NEFSC | 0 | | | 0.0 | | | 0.0 |
| | | **Total** | **1,975** | **6,368** | **375.5** | **17.0** | **241** | **247.8** | **1.0** |

**Table ZZ5.1-2 (continued).** Biological sampling intensity by state and season for recent years.

| | | | Commercial | | | | Recreational | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Season** | **State** | **Ages** | **Lengths** | **Landings (MT)** | **Lengths / MT** | **Lengths** | **Landings (MT)** | **Lengths / MT** |
| 2004 | Early | MA | | 0 | 0.0 | 0.0 | | 0.0 | 0.0 |
| | | RI | | 0 | 5.5 | 0.0 | | 0.0 | 0.0 |
| | | CT | | 0 | 0.3 | 0.0 | | 0.0 | 0.0 |
| | | NY | | 0 | 20.8 | 0.0 | 1 | 0.7 | 1.4 |
| | | NJ | | 0 | 35.4 | 0.0 | 6 | 48.6 | 0.1 |
| | | DE | 46 | 182 | 13.7 | 13.3 | | 0.0 | 0.0 |
| | | MD | 12 | 13 | 1.2 | 10.8 | | 0.0 | 0.0 |
| | | VA | 353 | 1,408 | 47.3 | 29.8 | 126 | 19.2 | 6.6 |
| | | NC | 300 | | | 0.0 | 31 | 36.5 | 0.8 |
| | | SC | | | | 0.0 | 11 | 1.7 | 6.5 |
| | | GA | | | | 0.0 | 0 | 0.8 | 0.0 |
| | | FL | | | | 0.0 | 15 | 9.4 | 1.6 |
| | | SEAMAP | 246 | | | 0.0 | | | 0.0 |
| | | CHESMAP | 263 | | | 0.0 | | | 0.0 |
| | | **Total** | | **1,603** | **124.3** | **12.9** | **190** | **116.9** | **1.6** |
| 2004 | Late | MA | | 0 | 0.0 | 0.0 | | 0.0 | 0.0 |
| | | RI | 4 | 0 | 11.9 | 0.0 | | 0.0 | 0.0 |
| | | CT | | 0 | 2.5 | 0.0 | | 0.0 | 0.0 |
| | | NY | | 0 | 47.4 | 0.0 | 4 | 8.0 | 0.5 |
| | | NJ | | 0 | 57.6 | 0.0 | 61 | 94.4 | 0.6 |
| | | DE | 552 | 0 | 9.6 | 0.0 | 13 | 3.1 | 4.2 |
| | | MD | 136 | 403 | 21.8 | 18.5 | 44 | 19.8 | 2.2 |
| | | VA | 55 | 1,848 | 101.7 | 18.2 | 45 | 27.4 | 1.6 |
| | | NC | 289 | | | 0.0 | 142 | 87.7 | 1.6 |
| | | SC | | | | 0.0 | 38 | 52.0 | 0.7 |
| | | GA | | | | 0.0 | 15 | 4.3 | 3.5 |
| | | FL | | | | 0.0 | 14 | 7.2 | 1.9 |
| | | SEAMAP | 316 | | | 0.0 | | | 0.0 |
| | | CHESMAP | 811 | | | 0.0 | | | 0.0 |
| | | NEFSC | 476 | | | 0.0 | | | 0.0 |
| | | **Total** | | **2,251** | **252.5** | **8.9** | **376** | **303.9** | **1.2** |
| 2005 | Early | MA | | 0 | 0.0 | 0.0 | | 0.0 | 0.0 |
| | | RI | 1 | 21 | 5.2 | 4.1 | 1 | 3.8 | 0.3 |
| | | CT | | 0 | 1.1 | 0.0 | | 0.0 | 0.0 |
| | | NY | | 0 | 9.8 | 0.0 | | 0.0 | 0.0 |
| | | NJ | | 0 | 22.7 | 0.0 | 2 | 8.3 | 0.2 |
| | | DE | 43 | 572 | 21.8 | 26.3 | 12 | 9.6 | 1.3 |
| | | MD | 18 | 18 | 0.8 | 23.4 | | 0.0 | 0.0 |
| | | VA | 217 | 1,000 | 55.4 | 18.0 | 294 | 5.0 | 58.8 |
| | | NC | 284 | | | 0.0 | 37 | 13.2 | 2.8 |
| | | SC | | | | 0.0 | 0 | 0.1 | 0.0 |
| | | GA | | | | 0.0 | 25 | 3.0 | 8.3 |
| | | FL | | | | 0.0 | 13 | 36.8 | 0.4 |
| | | SEAMAP | 185 | | | 0.0 | | | 0.0 |
| | | CHESMAP | 99 | | | 0.0 | | | 0.0 |
| | | **Total** | | **1,611** | **116.7** | **13.8** | **384** | **79.8** | **4.8** |

**Table ZZ5.1-2 (continued).** Biological sampling intensity by state and season for recent years.

| | | | Commercial | | | | Recreational | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Season** | **State** | **Ages** | **Lengths** | **Landings (MT)** | **Lengths / MT** | **Lengths** | **Landings (MT)** | **Lengths / MT** |
| 2005 | Late | MA | | 0 | 1.3 | 0.0 | | 0.0 | 0.0 |
| | | RI | 59 | 59 | 13.7 | 4.3 | | 0.0 | 0.0 |
| | | CT | | 0 | 1.6 | 0.0 | | 0.0 | 0.0 |
| | | NY | | 0 | 31.3 | 0.0 | 6 | 0.3 | 20.0 |
| | | NJ | | 0 | 71.9 | 0.0 | 131 | 513.3 | 0.3 |
| | | DE | 618 | 0 | 10.4 | 0.0 | 29 | 8.3 | 3.5 |
| | | MD | 260 | 455 | 13.3 | 34.1 | 30 | 4.0 | 7.5 |
| | | VA | 244 | 3,046 | 109.5 | 27.8 | 51 | 4.3 | 11.9 |
| | | NC | 277 | | | 0.0 | 117 | 58.4 | 2.0 |
| | | SC | | | | 0.0 | 31 | 42.6 | 0.7 |
| | | GA | | | | 0.0 | 4 | 0.5 | 8.0 |
| | | FL | | | | 0.0 | 25 | 8.5 | 2.9 |
| | | SEAMAP | 285 | | | 0.0 | | | 0.0 |
| | | CHESMAP | 1005 | | | 0.0 | | | 0.0 |
| | | NEFSC | 594 | | | 0.0 | | | 0.0 |
| | | **Total** | | **3,560** | **253.1** | **14.1** | **424** | **640.2** | **0.7** |
| 2006 | Early | MA | | 0 | 0.6 | 0.0 | | 0.0 | 0.0 |
| | | RI | 5 | 0 | 5.6 | 0.0 | | 0.0 | 0.0 |
| | | CT | | 0 | 2.7 | 0.0 | | 0.0 | 0.0 |
| | | NY | | 0 | 17.6 | 0.0 | 1 | 4.6 | 0.2 |
| | | NJ | 43 | 350 | 19.3 | 18.1 | 17 | 55.7 | 0.3 |
| | | DE | 79 | 117 | 10.5 | 11.2 | 5 | 3.5 | 1.4 |
| | | MD | | 3 | 0.3 | 9.1 | | 0.0 | 0.0 |
| | | VA | 360 | 1,738 | 45.2 | 38.5 | 51 | 22.5 | 2.3 |
| | | NC | 396 | | | 0.0 | 95 | 27.4 | 3.5 |
| | | SC | | | | 0.0 | 3 | 0.6 | 5.0 |
| | | GA | | | | 0.0 | 0 | 0.9 | 0.0 |
| | | FL | | | | 0.0 | 37 | 22.7 | 1.6 |
| | | SEAMAP | 120 | | | 0.0 | | | 0.0 |
| | | CHESMAP | 167 | | | 0.0 | | | 0.0 |
| | | **Total** | | **2,208** | **101.7** | **21.7** | **209** | **137.9** | **1.5** |
| 2006 | Late | MA | | 0 | 3.3 | 0.0 | | 0.0 | 0.0 |
| | | RI | 38 | 38 | 15.0 | 2.5 | 3 | 17.5 | 0.2 |
| | | CT | | 0 | 0.5 | 0.0 | | 0.0 | 0.0 |
| | | NY | | 0 | 51.7 | 0.0 | 4 | 1.7 | 2.4 |
| | | NJ | 256 | 379 | 74.6 | 5.1 | 69 | 203.6 | 0.3 |
| | | DE | 481 | 0 | 5.2 | 0.0 | 11 | 5.2 | 2.1 |
| | | MD | 180 | 494 | 14.4 | 34.3 | 0 | 0.3 | 0.0 |
| | | VA | 253 | 3,540 | 66.1 | 53.6 | 8 | 1.0 | 8.0 |
| | | NC | 341 | | | 0.0 | 149 | 35.8 | 4.2 |
| | | SC | | | | 0.0 | 75 | 3.0 | 25.0 |
| | | GA | | | | 0.0 | 1 | 0.5 | 2.0 |
| | | FL | | | | 0.0 | 13 | 10.6 | 1.2 |
| | | SEAMAP | 197 | | | 0.0 | | | 0.0 |
| | | CHESMAP | 550 | | | 0.0 | | | 0.0 |
| | | NEFSC | 995 | | | 0.0 | | | 0.0 |
| | | NEAMAP | 494 | | | | | | |
| | | **Total** | | **4,451** | **230.7** | **19.3** | **333** | **279.2** | **1.2** |

**Table ZZ5.1-2 (continued).** Biological sampling intensity by state and season for recent years.

| | | | Commercial | | | | Recreational | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Season** | **State** | **Ages** | **Lengths** | **Landings (MT)** | **Lengths / MT** | **Lengths** | **Landings (MT)** | **Lengths / MT** |
| 2007 | Early | MA | | | 0.2 | 0.0 | | 0.0 | 0.0 |
| | | RI | | | 4.1 | 0.0 | | 0.0 | 0.0 |
| | | CT | | | 0.6 | 0.0 | | 0.0 | 0.0 |
| | | NY | | | 14.2 | 0.0 | | 0.0 | 0.0 |
| | | NJ | | | 53.6 | 0.0 | 8 | 23.5 | 0.3 |
| | | DE | | | 9.9 | 0.0 | 2 | 0.6 | 3.3 |
| | | MD | | | 1.9 | 0.0 | | 0.0 | 0.0 |
| | | VA | | 997 | 94.1 | 10.6 | 4 | 6.6 | 0.6 |
| | | NC | | | | 0.0 | 14 | 3.9 | 3.6 |
| | | SC | | | | 0.0 | 25 | 2.3 | 10.9 |
| | | GA | | | | 0.0 | 4 | 1.3 | 3.1 |
| | | FL | | | | 0.0 | 11 | 8.8 | 1.3 |
| | | SEAMAP | | | | 0.0 | | | 0.0 |
| | | CHESMAP | | | | 0.0 | | | 0.0 |
| | | **Total** | | **997** | **178.6** | **5.6** | **68** | **47.0** | **1.4** |
| 2007 | Late | MA | | | 0.0 | 0.0 | | 0.0 | 0.0 |
| | | RI | | | 5.3 | 0.0 | | 0.0 | 0.0 |
| | | CT | | | 0.3 | 0.0 | | 0.0 | 0.0 |
| | | NY | | | 25.1 | 0.0 | 0 | 3.7 | 0.0 |
| | | NJ | | | 20.2 | 0.0 | 30 | 111.2 | 0.3 |
| | | DE | | | 1.2 | 0.0 | 6 | 1.4 | 4.3 |
| | | MD | | | 6.2 | 0.0 | 7 | 8.8 | 0.8 |
| | | VA | | 1,831 | 56.8 | 32.2 | 5 | 15.2 | 0.3 |
| | | NC | | | | 0.0 | 65 | 53.0 | 1.2 |
| | | SC | | | | 0.0 | 150 | 18.6 | 8.1 |
| | | GA | | | | 0.0 | 5 | 0.4 | 12.5 |
| | | FL | | | | 0.0 | 27 | 51.3 | 0.5 |
| | | SEAMAP | | | | 0.0 | | | 0.0 |
| | | CHESMAP | | | | 0.0 | | | 0.0 |
| | | NEFSC | | | | 0.0 | | | 0.0 |
| | | **Total** | | **1,831** | **115.1** | **15.9** | **295** | **263.6** | **1.1** |

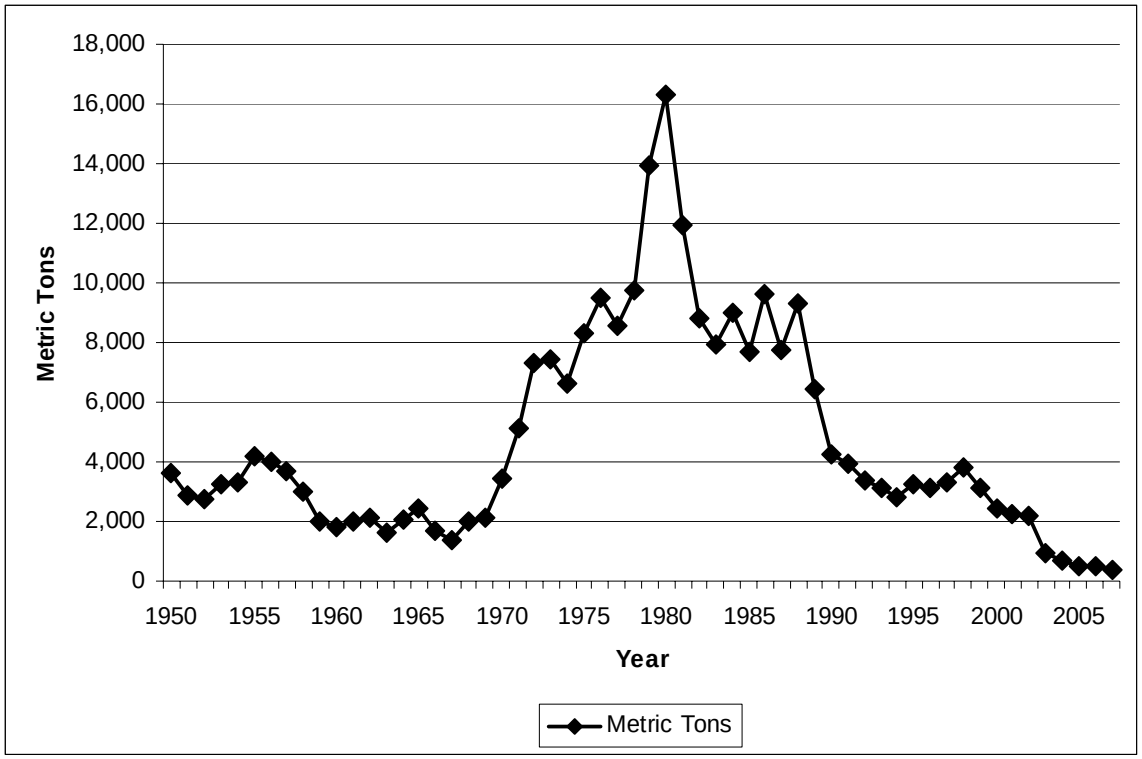



**Figure ZZ4.6-1.** Commercial harvest of weakfish on the Atlantic coast.

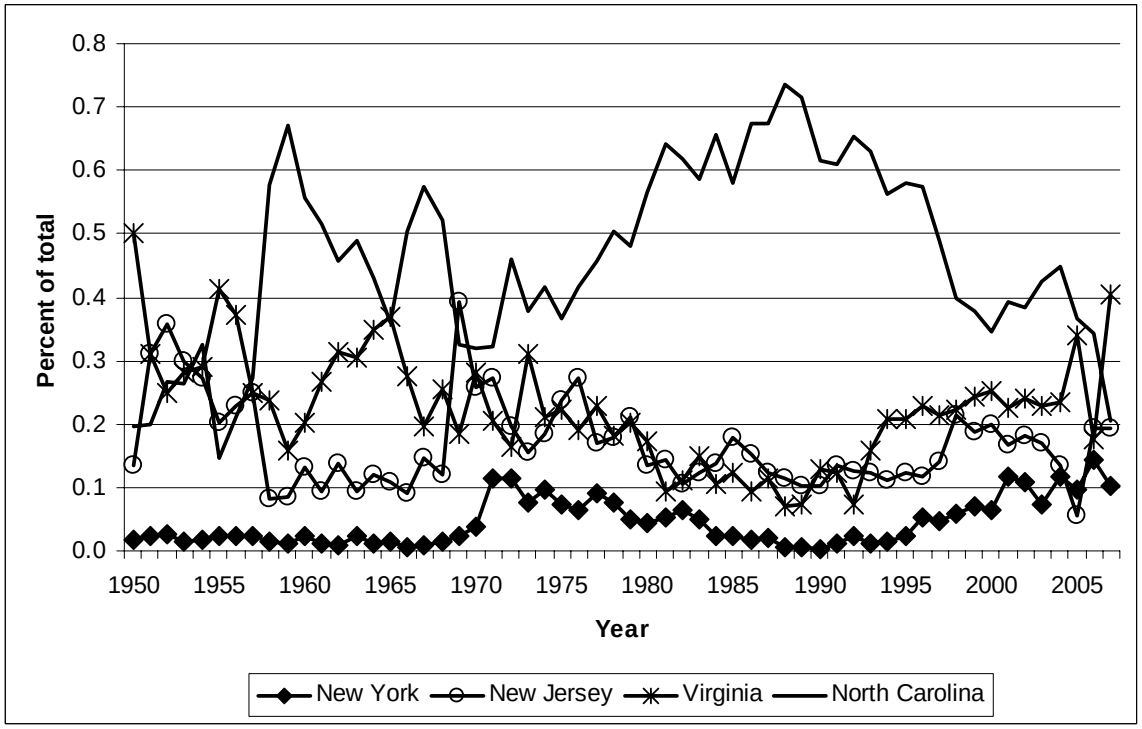



**Figure ZZ4.6-2.** Proportion of annual commercial weakfish harvest by dominant states.

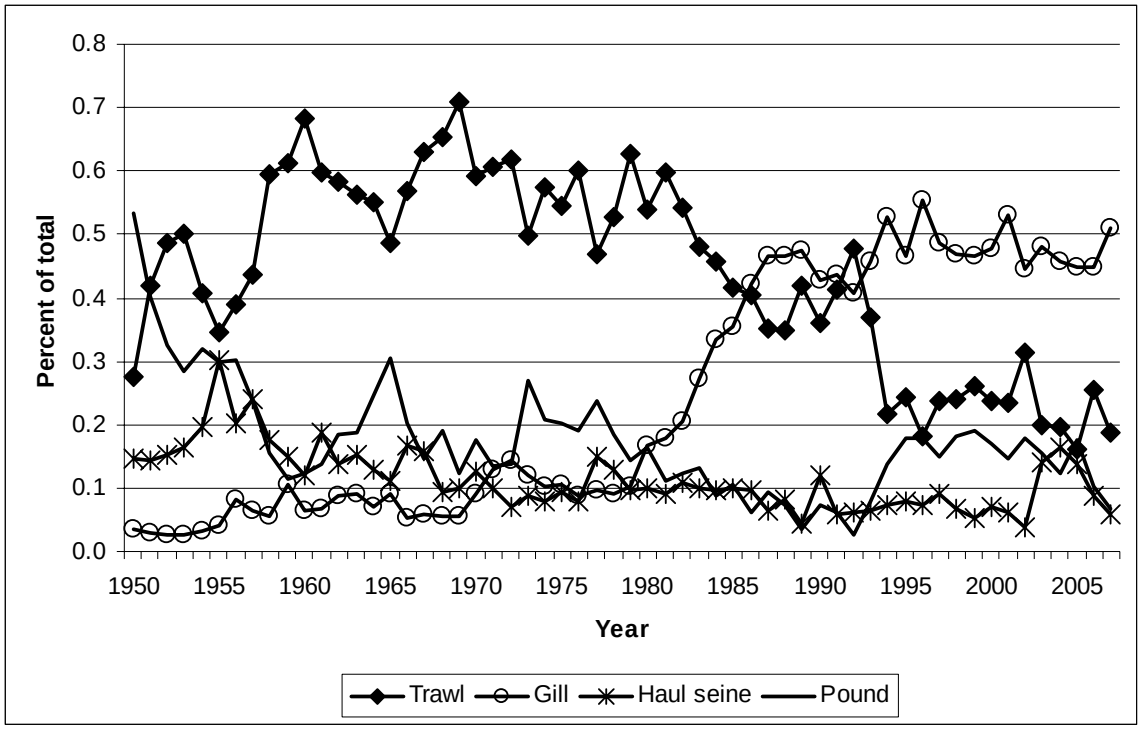



**Figure ZZ4.6-3.** Proportion of annual commercial weakfish harvest by dominant gears.

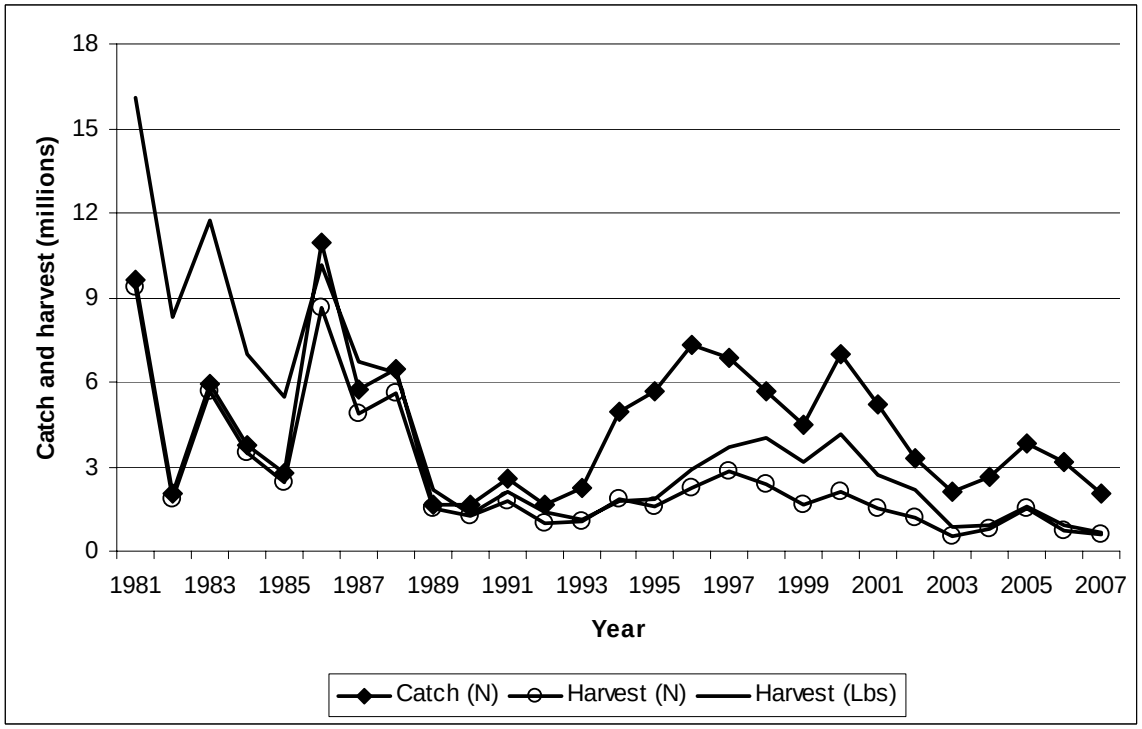



**Figure ZZ4.6-4.** Recreation catch (numbers) and harvest (numbers and pounds) of weakfish on the Atlantic coast.

**Figure 4.6-5.** Proportion of annual recreational weakfish harvest by dominant states. (Should this be a table instead?)

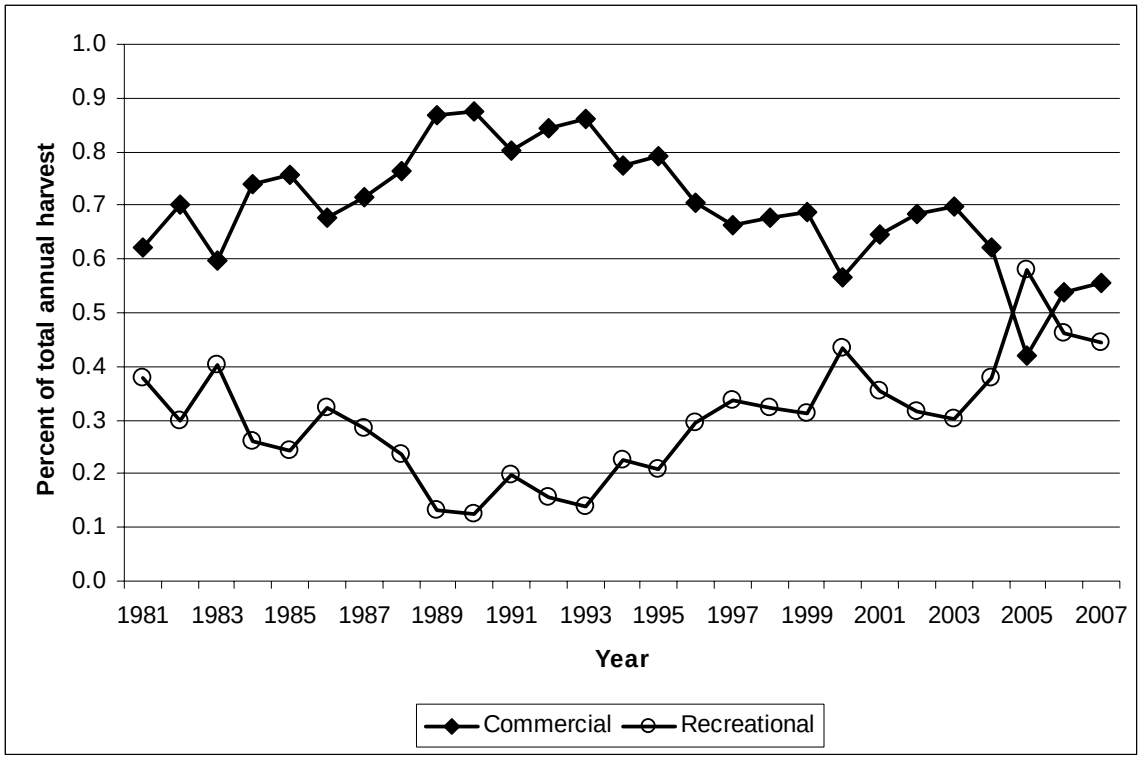
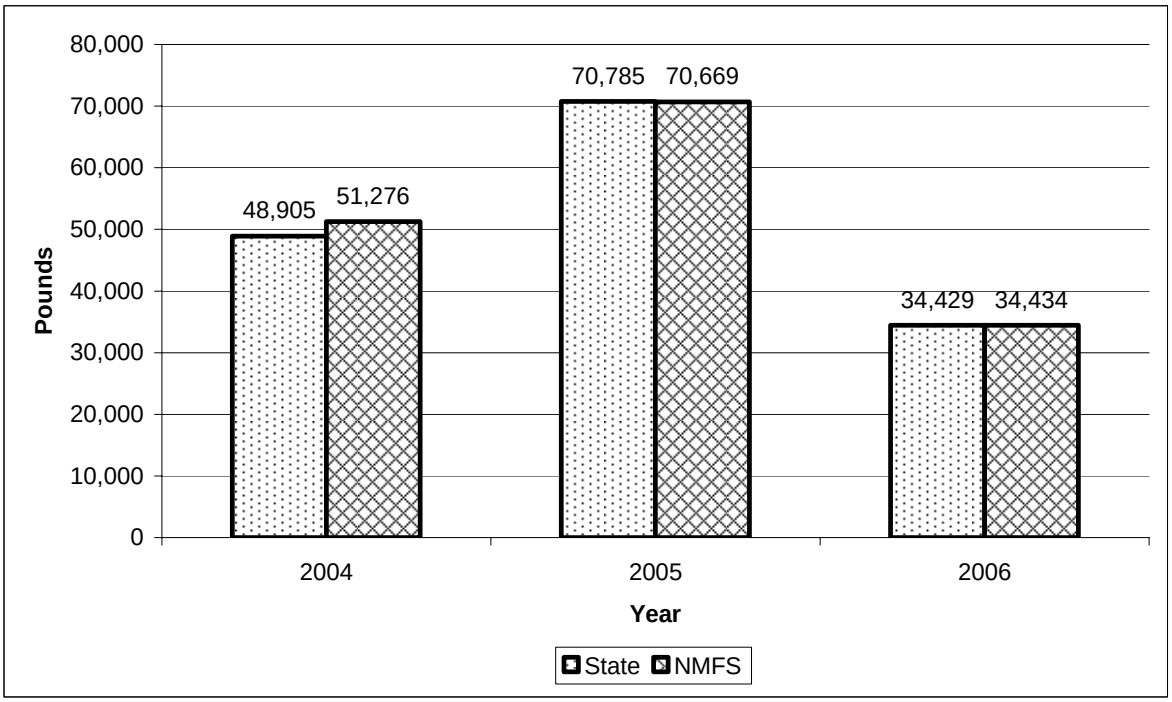



**Figure 4.6-6.** Proportion of total annual weakfish landings (excluding discards) by the commercial and recreational sectors.

**Figure 5.1-1.** Comparison of state and federally reported landings on an annual basis for A) Delaware and B) Virginia.

A)




B)

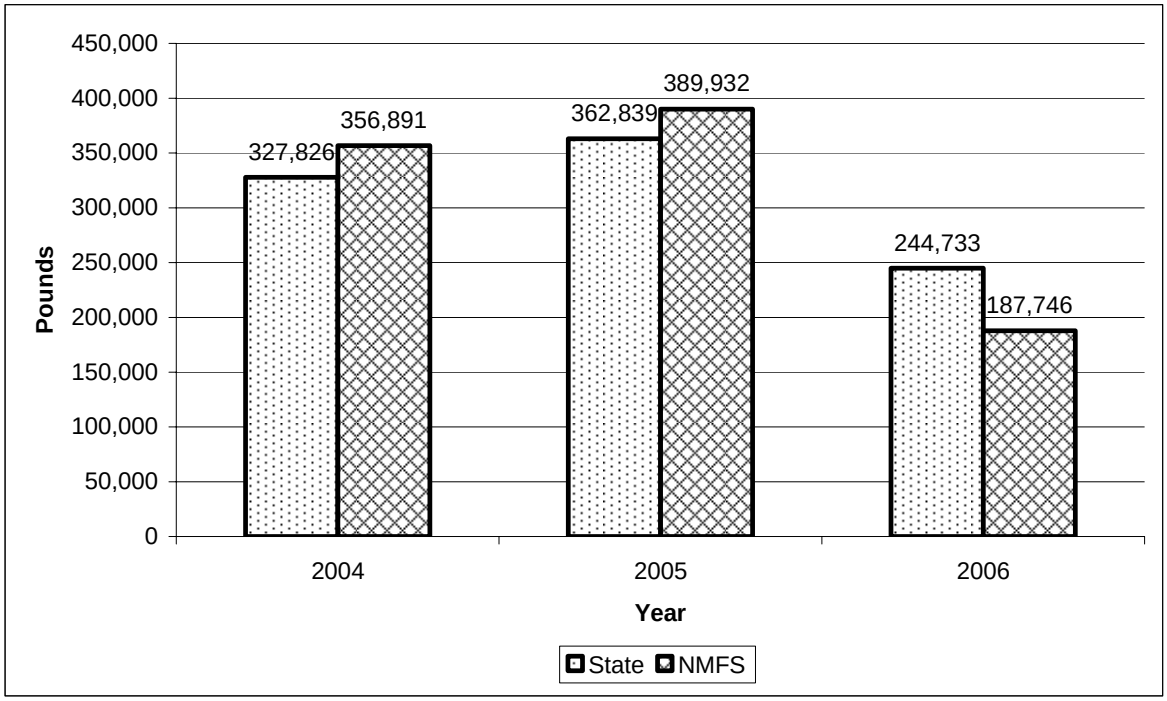
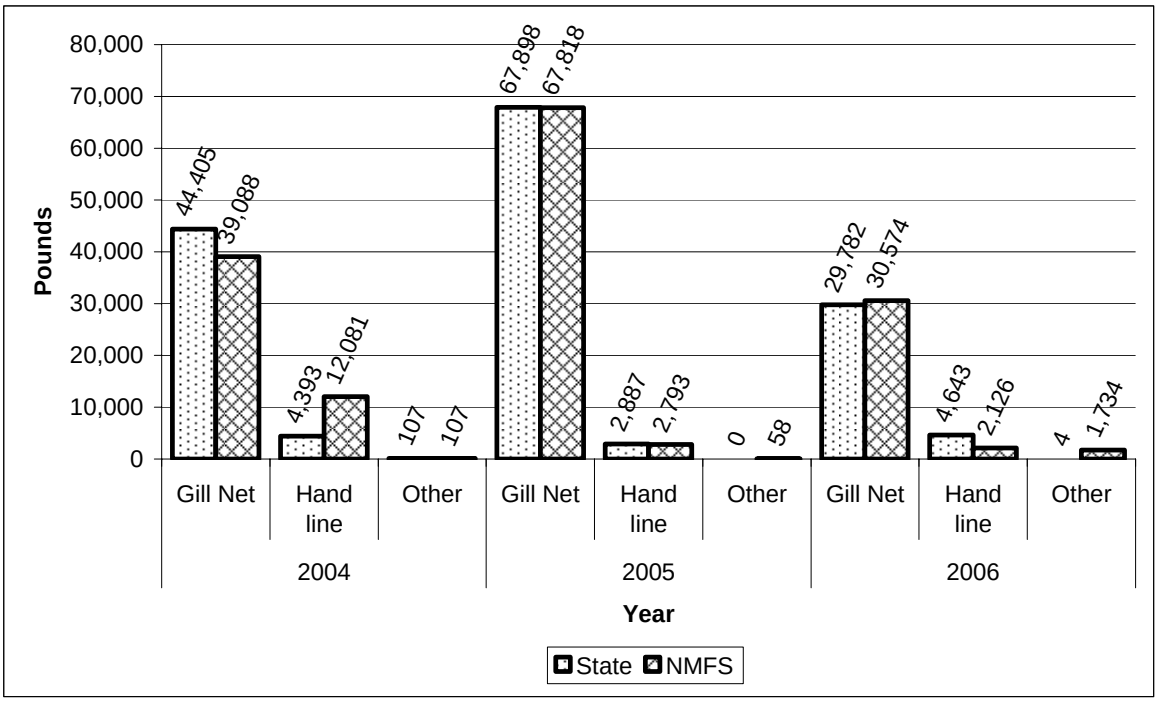
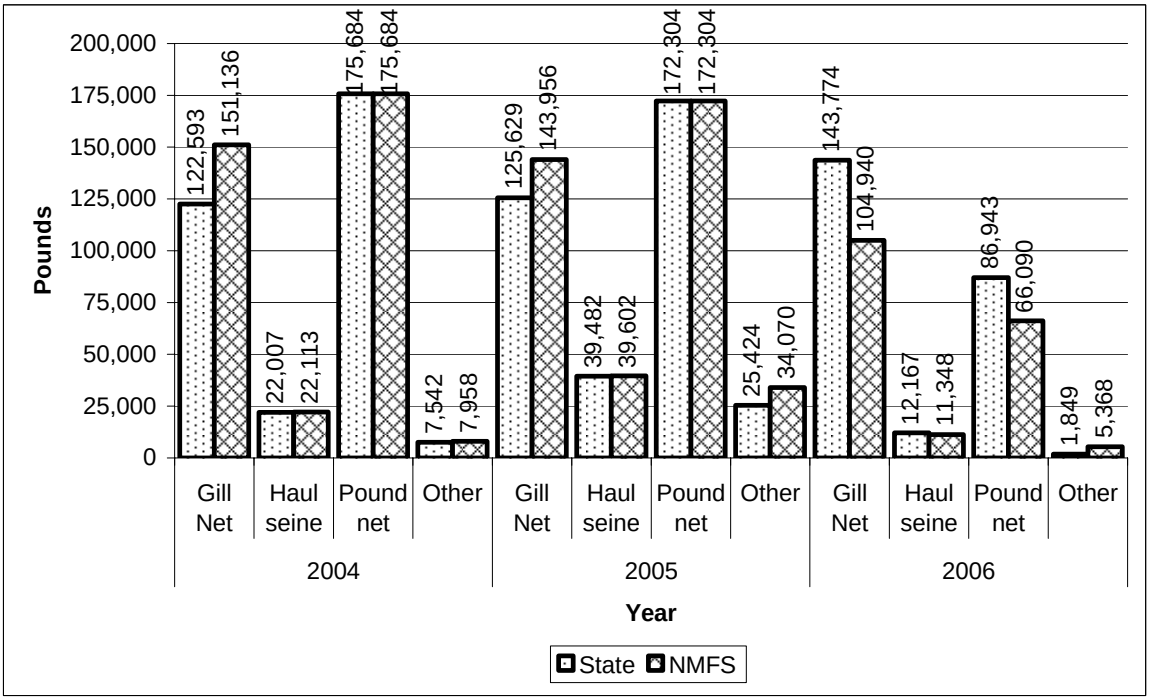


**Figure 5.1-2.** Comparison of state and federally reported data by gear for A) Delaware and B) Virginia.

A)




B)



Working Paper 2

# Weakfish
# Biomass Dynamic Models Summary

By
Jim Uphoff

Data Poor Stocks Working Group Meeting
December 8-12, 2008
Woods Hole, MA

*This information was distributed solely for the purpose of pre-dissemination peer review at the December 2008 Data Poor Stocks Working Group Meeting. It is not being formally disseminated by NOAA and it does not represent any final agency determination or policy.*

FOR PEER REVIEW ONLY

**WEAKFISH WP#2 (11/24/08)**

# Biomass dynamic models and external factor hypothesis testing

Jim Uphoff

November 13, 2008

Note that a four index logistic biomass dynamic model (fishing only) was developed and rejected by the TC as implausible (stock at carrying capacity and very low F). This summary describes model development after that effort.

Indices
Last time
One index.
MRFSS weight per trip 1981-2003.
Released fish and harvest mean weights based on harvest mean weight.

This time
Three indices
1. MRFSS weight per trip 1981-2006.
    Released fish assigned headboat release weight (constant at 0.15 kg).
    Harvested fish use harvest mean wt.
2. Two survey indices; mean wt confined to exploitable sizes (25 cm+)
2. Delaware trawl survey kg per trawl 1990-2006.
3. NJ August positive tows * mean wt 1989-2006.
4. Indices standardized as Z transformation+2 for time period in common (1990-2006).
5. Indices compatible: positively correlate with each other, landings, converged portion of best previous VPA.

Harvest from NMFS and MRFSS

Discards
Recreational (number discard estimate*mortality* mean wt).
Last time – 20% release mortality and mean wt = harvest wt.
This time – 10% release mortality and mean wt = head boat estimate (constant 0.15 kg).

Commercial
Last time – Annual discard ratio estimates.
This time – All year discard ratio estimates.

External Factors
Based on previous analyses of environmental and predator/competitor candidates by Crecco or Uphoff.
Candidate external factors considered: striped bass, spiny dogfish, Atlantic croaker, bluefish, summer flounder, forage fish, sea temperature, NAO.
Selection of final candidates considered spatial-temporal overlap, diet information, statistical analysis, modeling.

Previous Final External
Striped bass age 2+ biomass from VPA (1981 = 1982-1984 mean).

Current Final External
Striped bass age 2+ biomass from ASMFC SCAM (1981 = 1982-1984 mean).
Menhaden age 1+ biomass from ASMFC forward projection.

Hypotheses
Tested with 3 to 5 parameter models.

Last time 3 hypotheses
1. Logistic production fc.
2. Fishing only (1 of 3).
3. Fishing + striped bass Type 3 predator-prey fc (2 of 3).
3. Fishing + striped bass depensatory fc; bass*scalar (miss-labeled as Type 1 fc; 3 of 3).

This time 12 hypotheses
1. Logistic and Gompertz production fc's with 6 variations each (2 fc*6 external = 12).
2. Fishing only (1 of 6 external).
3. Fishing + Type 1-3 predator-prey fc (2-4 of 6 external).
4. Fishing + striped bass depensatory fc; bass*scalar (5 of 6 external).
5. Fishing + depensatory as menhaden:bass fc (6 of 6 external); formalizes hypothesis developed in previous biomass dynamic predator-prey.

Last time goodness of fit
SSQ, r-square, residuals, biology.

This time goodness of fit
AICc added to above.

Last time relative F vs model F
Harvest related losses / MRFSS index rescaled to Converged VPA (Crecco's rescaled relative F).

This time relative F vs model F
(Harvest related losses * model index scalar) / mean Z+2 index.
Crecco's rescaled relative F can be added once finalized.

Implemented in spreadsheet with Evolver genetic algorithm (Palisade Corporation) both assessments.

Minimize lognormal error in predicted and observed indices.

Output
F, predation/competition losses, nonequilibrium M, biomass, surplus production, production, equilibrium and non-equilibrium reference points.

Projections can be made.

Working Paper 3

# Weakfish
# Predation Models Summary

Data Poor Stocks Working Group Meeting
December 8-12, 2008
Woods Hole, MA

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**-For Peer Review Only-** **WEAKFISH WP#3**

**(11/24/08)**

# Weakfish Predation Models Summary

Additional analyses for the weakfish stock assessment include several new and updated approaches. Time series (1981-2007) of weakfish age aggregated (ages 1+) *F* and stock biomass (mt) estimates were derived in the new assessment based on blended relative abundance indices from the MRFSS mid-Atlantic private boat fishery, the August NJ trawl survey, and the DE trawl survey.

1) New Analysis - Ricker stock recruitment (S-R) modeling that included the coast-wide blended recruitment index for the 1981 to 2007 year-classes against spawning stock size (mt) that consisted of the age aggregated (ages 1+) biomass (mt) estimates from the index-based analysis. This nonlinear model was run alone and in combination with a blended index of predation (Tpred) consisting of the time series of coast-wide striped bass and spiny dogfish abundance. When the Ricker model was run without predation effects, the statistical fit to the S-R data was strong (high coeifficient of determination and low standard errors about the parameter estimates), but a significant serial correlation in the residuals was noted, indicating serious process error. When the Ricker model was fitted to S-R data in the presence of Tpred, the fit was strong, the precision of the parameter estimates was higher, and most importantly, the residual pattern became random over time, suggesting that enhanced predation of age 0 weakfish (emergence of a demographic bottleneck) by striped bass and spiny dogfish is an important process in the current weakfish stock-recruitment relationship.

2) New Analysis - Comprehensive screening of potential candidate predators (striped bass, spiny dogfish, bluefish and Summer flounder), environmental factors (mean summer (July-September) sea surface water temperature and deviations in the winter North Atlantic Oscillation index) and fishing-related effects (discards (mt) and discard-related F) against several response variables (weakfish surplus production, index of weakfish biomass and juvenile weakfish mortality) using a Pearson correlation matrix and stepwise multiple regression methods in SAS. Results revealed that only striped bass and spiny dogfish abundance was significantly ($P < 0.001$) linked to the recent (post 1998) rise in weakfish juvenile mortality and corresponding decline in weakfish biomass and surplus production.

3) Updated Steele-Henderson (S-H) model runs for Atlantic coast weakfish with and without predatory (Tpred) effects from 1981 to 2007. Another run with the S-H model includes the potential effects of declining menhaden abundance, as a secondary prey effect, on the recent rise in predatory mortality of striped bass on weakfish.

4) Updated (through 2007) equilibrium and non-equilibrium overfishing (Fmsy, Bmsy) estimates and their 95% confidence limits for weakfish based on results from the updated Steele-Henderson model. Results reveal that Atlantic coast weakfish is severely depleted by enhanced predatory mortality but is not overfished.

Working Paper 4

# Weakfish
# Stock Assessment Report

Data Poor Stocks Working Group Meeting
December 8-12, 2008
Woods Hole, MA

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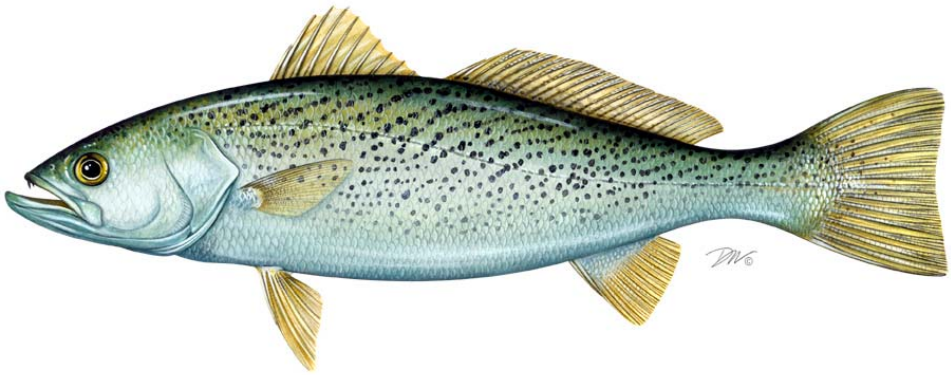
# Atlantic States Marine Fisheries Commission

## *2006 Weakfish Stock Assessment*

Weakfish Stock Assessment Report
Terms of Reference and Advisory Report
Technical Committee Supplemental Material



**December 2006**

*Working towards healthy, self-sustaining populations for all Atlantic coast fish species or successful restoration well in progress by the year 2015*

## ACKNOWLEDGEMENTS

The Atlantic States Marine Fisheries Commission (ASMFC) thanks all of the individuals who contributed to the development of the weakfish stock assessment and the peer review of the assessment. The Commission extends its appreciation to the Weakfish Stock Assessment Peer Review Panel for its efforts in evaluating the stock assessment and developing the Terms of Reference and Advisory Report: Dr. Brian Rothschild, Panel Chair, University of Massachusetts - Dartmouth; Dr. Steven Cadrin, NOAA/UMass Cooperative Marine Education and Research Program; Dr. Steven Martell, University of British Columbia; and Dr. Ransom Myers, Dalhousie University.

The Commission also thanks the ASMFC Weakfish Technical Committee (TC) and Weakfish Stock Assessment Subcommittee (SAS) for developing the consensus stock assessment report, especially Dr. Desmond Kahn (Chair, Weakfish Stock Assessment Subcommittee; Delaware Department of Natural Resources), Dr. Vic Crecco (Connecticut Department of Environmental Protection) and Jim Uphoff (Chair, Weakfish Technical Committee; Maryland Department of Natural Resources) for their presentations of the stock assessment to the Peer Review Panel. Additional members of the Weakfish Stock Assessment Subcommittee include Jeffrey Brust (New Jersey Department of Environmental Protection), Brian Murphy (Rhode Island Department of Environmental Management), Robert O'Reilly (Virginia Marine Resources Commission), Lee Paramore (North Carolina Division of Marine Fisheries), and Douglas Vaughan (National Marine Fisheries Service – Beaufort). Additional gratitude is due to the TC and SAS members that continued work on the assessment after the peer review to complete the follow-up tasks assigned by the Weakfish Management Board.

Appreciation is given to the Commission staff dedicated to the performance of the Weakfish Stock Assessment Peer Review and the finalization of this report, specifically – Brad Spear, Joe Grist, and Patrick Kilduff.

This is a report of the Atlantic States Marine Fisheries Commission pursuant to U.S. Department of Commerce, National Oceanic and Atmospheric Administration Award No. NA05NMF4741025.

# PREFACE

This document contains the following reports:

**Section A – Stock Assessment**
Weakfish Stock Assessment Report for Peer Review (Part 1)
(ASMFC Weakfish Stock Assessment Subcommittee, February 2006)

Weakfish Stock Assessment Report for Peer Review (Part 2) – An Ecological Assessment of Weakfish: Examination of Fishing and Trophic Effects on the Recent Stock Decline
(ASMFC Weakfish Stock Assessment Subcommittee, February 2006)

**Section B – Peer Review**
Terms of Reference and Advisory Report to the Weakfish Stock Assessment and Peer Review
(ASMFC Weakfish Stock Assessment Peer Review Panel, April 2006)

**Section C – Supplemental Material Requested by the Weakfish Management Board**
Implementation of 40th SARC Recommendations
(ASMFC Weakfish Technical Committee, June 2006)

Summary of Weakfish Technical Committee (TC) agreements and disagreements with the 2006 peer review and the record of implementing recommendations of the 40th SARC
(ASMFC Weakfish Technical Committee, July 2006)

Executive Summary: How Much Additional Discarding and Under-Reporting are Necessary to Cause the Decline in Weakfish?
(Uphoff, J., June 2006)

Executive Summary: Estimating at-sea discards of weakfish using NEFSC observer database
(ASMFC Weakfish Technical Committee, July 2006)

The weakfish population structure along the Atlantic coast: a literature review
(Munyandorero, J., July 2006)

Overview of the Weakfish Resource
(Uphoff, J., August 2006)

What's Next with Weakfish? Fishery Status & Board Requests (presentation)
(ASMFC Weakfish Technical Committee, August 2006)

## EXECUTIVE SUMMARY

The first peer review of a weakfish stock assessment was conducted in 1996 by the Stock Assessment Review Committee (SARC) at the 26th Northeast Regional Stock Assessment Workshop (SAW). The Review Committee did not approve the assessment and recommended that future assessments be conducted using ADAPT VPA. (Assessments up to that time had employed CAGEAN and Extended Survivor VPA, among other catch-at-age models.) The subsequent assessment, including data through 1998, was peer reviewed at the 30th SAW/SARC, which concluded that results of the ADAPT VPA could be used to calculate biological reference points and that figures illustrating the expanded size and age composition of weakfish would be useful for developing management advice. However, the Review Committee did find a noticeable retrospective bias in the ADAPT results which overestimated stock size and underestimated fishing mortality in the last few years.

A stock assessment update was conducted in 2002 (with data through 2000) using the SARC-approved methodology. Although this assessment was not peer reviewed, the Weakfish Technical Committee (TC) expressed concern about a strong retrospective bias that may have resulted from some shortcomings in the assessment data and model.

In 2003, the Weakfish Stock Assessment Subcommittee (SAS) began preparation for a 2004 peer review through the 40th SAW. Model results using the previously approved SARC methodology still exhibited a strong retrospective pattern, and results from both ADAPT VPA and a biomass dynamic model portrayed the stock as at very high levels, carrying capacity in the case of the biomass dynamic model, with very low fishing mortality. In light of the fishery landings having dropped to record low levels, the model results were not deemed credible.

For these reasons, the SAS deemed the ADAPT VPA methodology as insufficient to characterize the weakfish resource and proceeded to investigate alternative assessment methods. Although the revised weakfish assessment was incomplete at the time of the peer review, the SARC agreed to review the work and provide guidance on issues that were impeding the progress of the assessment, such as the inconsistency between survey indices, some of which portrayed an increase in abundance, and fishery-dependent indices of abundance and catch-at-age, which had declined significantly.

The Review Committee agreed with the SAS that the results of the work in progress, although using the same approach as the SARC-approved assessment in 1999, were not suitable for management at present. The Review Committee indicated that they felt the problem was conflicting data, and expressed skepticism about the reliability of some survey indices, especially the Northeast Science Center Fall Survey. Recommendations from the SARC proved to be useful, and some were incorporated into the stock assessment. The assessment was also expanded to include some alternative approaches previously explored by the SAS in the 2002 update process.

The stock assessment was completed in February 2006 (See Section A). The assessment was submitted to the Commission and was evaluated through the Commission's external peer review process on March 20-22, 2006 in Providence, RI. The Peer Review Panel consisted of four

fisheries biologists with expertise in population dynamics and stock assessment methods. The stock assessment was reviewed relative to the following Terms of Reference:

1. Characterize commercial and recreational catch including landings and discards.
2. Review adequacy and uncertainty of fishery-independent and dependent indices of relative abundance.
3. Review the appropriateness of constant and variable natural mortality (M) estimates in the assessment.
4. Review the estimates of fishing mortality (F), spawning stock biomass, and total stock biomass for 1981-2004, and characterize the uncertainty of these estimates.
5. Review the estimated biological reference points, as appropriate.
6. Review stock projections.
    - Review the projection of impacts on the stock of recent estimated rise in fishing mortality.
    - Review the projection of stock response to reductions in fishing mortality given the estimated increase in natural mortality.
7. Make research recommendations for improving data collection and assessment.

The Panel reviewed the 2006 Weakfish Stock Assessment and did not endorse the recommendations within the assessment report regarding stock status of weakfish along the Atlantic coast (see Section B). The Panel identified several issues that required additional work or attention by the Weakfish TC before they would support its use for management purposes. In particular, the Panel had concerns regarding stock structure, age composition data, and fishery discards.

The Weakfish Management Board directed the Weakfish TC to address the issues identified by the Review Panel. Specifically, the Board tasked the TC with furthering investigating stock structure and discards; determining agreements and disagreements among the assessment report, the peer review panel report, and the 40$^{th}$ SARC report; and providing an account of the implementation of recommendations from the 40$^{th}$ SARC.

**Final Results**

In August 2006, the Weakfish TC provided a response to the Board tasks (see Section C). Based on these responses, the TC's analyses, and significant evidence, **the Board accepted the following five points for management use**:

1) the stock is declining,
2) total mortality is increasing,
3) there is not much evidence of overfishing,
4) something other than fishing mortality is causing the decline in the stock, and
5) there is a strong chance that regulating the fishery will not, in itself, reverse stock decline.

# WEAKFISH STOCK ASSESSMENT REPORT FOR PEER REVIEW (PART 1)

**February 2006**

**BY**

**THE ASMFC WEAKFISH STOCK ASSESSMENT SUBCOMMITTEE**

Desmond M. Kahn, Chair
Jim Uphoff, Vice-Chair
Victor Crecco
Douglas Vaughan
Brian Murphy
Jeffrey Brust
Robert O'Reilly
Lee Paramore

Note: an external peer review panel did not endorse the recommendations within this assessment report. For more information see the Peer Review Report (Section B), and the Weakfish Technical Committee's responses to that report (Section C).

**ACKNOWLEDGEMENTS**

Brad Spear of ASMFC has been helpful in many ways. We appreciate the substantial work done by Harry Rickabaugh of Maryland DNR and Patrick Kilduff of the ASMFC staff in developing the catch at age and weight at age estimates. We thank Robin Cook, Peter Shelton, Norman Hall, John Casey and Terry Smith of the 40th SARC for their helpful comments and analysis. Alan Seaver of the North East Fisheries Science Center has been very helpful on ADAPT software issues.

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## EXECUTIVE SUMMARY

This assessment covers the period of 1982 through 2003 for catch-at-age analysis and biomass dynamic modeling and 1982-2004 or, conditionally, 2005, for some other approaches. The last peer-reviewed assessment covered 1982-1998 (NEFSC 2000). In 2002, an update was conducted which covered 1982 – 2000.

Recreational landings have been in decline since 2000, while commercial landings have been in decline since 1998. From 2000 through 2003, commercial landings were the lowest in the period. The 2003 recreational landings were the lowest in the period; the previous low point was in 1993. These declines suggest that abundance has declined. One or two of the research trawl surveys, however, contradict the picture that abundance has declined to very low levels, but those surveys show evidence of large year-to-year effects in weakfish availability, which reduces their value as indicators of trends in relative abundance. All variants of the recreational CPUE indices have been declining since about 1998.

Cohort catch curves of the catch-at-age matrix indicated that mortality had been relatively high for cohorts from the 1980s, declined to low levels for year classes born in the early 1990s, but then increased to very high mortalities for year-classes produced from the mid-late 1990s. Since Z was about 1.4 for recent year classes, subtraction of an assumed constant M = 0.25 indicated that F has increased greatly for these cohorts to levels of 1.15 or so. This pattern in Z of a decline in the early 1990 year classes followed by an increase was significantly correlated with the pattern found in cohort catch curve estimates of the Delaware trawl survey indices of relative abundance.

As in past assessments using ADAPT, retrospective bias was present in all ADAPT runs, meaning estimates of variables such as F and stock size were unstable for recent years, changing as additional years of data are added or subtracted. These biases occurred in opposite directions when either survey indices or recreational CPUE indices were employed. Model configurations using recreational CPUE indices of relative abundance as tuning indices, however, showed more recent stability than runs without these indices. Depending on the tuning indices selected, stable estimates of F and biomass are available from 1982 through about 1997 to 2000. Assuming M = 0.25, estimated fully-recruited F dropped sharply in 1995. For run #14 using trawl indices for tuning, F dropped to 0.26 in 1995, then rose to 0.40 in 1996 and about 0.36 in 1997 and 1998. After that, retrospective bias makes estimates unstable. The estimates of F decline to 0.03 in 2003, however. For run #20 using the recreational CPUE indices, fully recruited F dropped to 0.32 in 1995, then increased to 1.06 in 2000, the last year with relatively stable estimates. For this run, in contrast to the run with trawl survey indices, estimated F climbs to 1.6 – 1.5 in 2002-2003. Estimated SSB from ADAPT climbed above the SSB threshold estimated in the currency of the 2002 assessment update of 14,400 metric tons in 1994 with the trawl survey indices (run #14) and increased to 31,628 metric tons in 1997, higher than any previous year. Later year's estimates are unstable, but climb to 125,843 mt by 2003. For the run tuned to the recreational CPUE indices (run #20), SSB approached the threshold from below in 1994 and 1996, but did not exceed it until 1996. SSB climbed to a peak in 1997 of 18,752 mt, then declined to 6,260 mt in 2000. Estimates for late years are unstable, but declines by 2003 to 2,573 mt, lowest by far in

the time series. The lack of stable recent estimates from ADAPT considerably reduces its value for management.

When trawl survey exploitable biomass per tow was used as an index of stock biomass, a biomass dynamic model indicated that the stock reached very high levels of 37,000 – 39,000 mt by 1997 and remained there through 2003, near carrying capacity. Estimated biomass-weighted F from this model was very low in recent years (0.11 – 0.17 between 1994-2000), then dropped rapidly to 0.03 by 2003.

Reviewers from the 40th SARC reviewed the assessment as work in progress prior to development of the ADAPT runs with the recreational CPUE indices. They concluded that the models tuned to the trawl surveys revealed problems with the survey data and recommended extensive analysis of this data. Following their recommendation, we subjected each index to cohort catch curve analysis and found that two of the surveys produced negative Z estimates for recent cohorts.

We were forced to investigate alternative approaches due to the instability of recent years' estimates of F and SSB from ADAPT, and the unrealistic estimates from the biomass dynamic model and ADAPT tuned to survey indices. These models estimated recent extremely high biomass and very low F, despite severe declines in fishery catches. As a result, we estimated trends in fishing mortality as relative F, calculated as annual catch divided by an index of relative abundance averaged over two years. The index was a version of recreational catch per trip in weight (including discards), which had the advantage of great geographical coverage in contrast to most of the survey indices. One valuable attribute of relative F analysis is that it does not make assumptions about the amount or constancy of natural mortality. The general trends in relative F were confirmed when trawl survey exploitable biomass indices were used in place of the recreational CPUE index.

Biomass-weighted relative F estimates from 1982-2004 closely followed the trend in ages 1-5 biomass-weighted F from the converged portion of the ADAPT VPA models. We then converted these relative F estimates to absolute values of F by scaling them to the VPA F estimates for 1987-1991. Biomass weighted fishing mortality (FWt) estimates (ages 1+) on weakfish rose steadily from about 0.41 in 1982 to peak levels in 1988 (FWt = 1.08). The FWt estimates remained relatively high (FWt range: 0.60 to 0.81) from 1989 to1992 (Table 2), then declined steadily to below the 0.40 level in most years from 1993 to 2005. The 2004 and 2005 FWt estimates were around 0.25.

With time series of F and catch, we estimated stock biomass as catch/F. Biomass was high initially (34,010 mt in 1982), remained relatively high in the mid-1980s, then declined sharply in 1989 and remained below 10,000 mt through 1993. Stock biomass than began to rebuild, reached a secondary peak in 1998 (28,858 mt) and declined steadily to levels similar to those of the early 1990s, with the lowest level of the time series in 2004 (5,739 mt). We then developed a time series of surplus production estimates which indicated some recent years with negative production.

An external Gompertz production model provided a good fit ($R^2 = 0.68$) to the biomass data with statistically significant ($P < 0.05$) r and K parameter estimates. The resulting overfishing thresholds (Fmsy, Bmsy) for weakfish of 0.32 and 25,259 mt, respectively, were similar in magnitude to previous estimates. However, this production model consistently over predicted weakfish biomass from 1998 to 2005 by 10 to 50%. A full Steele-Henderson (S-H) production model including striped bass as a major predator was fitted by nonlinear least squares regression and also by iterative re-weighted least squares regression. Both S-H models provided very good fits ($R^2 = 0.88, 0.94$) to the biomass and predation data with statistically significant ($P < 0.05$) r, K, c and A parameter estimates. Overall, the S-H model was not only a better fit to weakfish biomass than the basic Gompertz model, but it also estimated the r and K parameters with much higher precision, particularly from iterative re-weighting.

The resulting weakfish overfishing thresholds (Fmsy, Bmsy) from the nonlinear least squares S-H model for weakfish were 0.59 and 21,179 mt, respectively. The overfishing thresholds (Fmsy,Bmsy) based on the iterative re-weighted S-H model were 0.55 and 23,400 mt, respectively and had higher precision than the nonlinear least squares fit. Moreover, unlike the severe residual pattern evident from 1998 to 2004 in the Gompertz model fit, there is little if any systematic residual pattern from the S-H model fitted by iterative re-weighting. The biomass-weighted F estimates after 1995 were all well below the overfishing definition (Fmsy = 0.55) from the S-H model. Weakfish biomass has been well below Bmsy = 23,400 mt since 2000 despite low and stable fishing mortality rates from 1995 to 2005.

Total mortality (Z) on Atlantic coast weakfish has risen steadily since about 1998, whereas fishing mortality (F) rates based on relative F were relatively low and stable during this period. Since total mortality (Z) each year was the sum of fishing and natural mortality, the recent rise in Z and ensuing failure in weakfish surplus production were more likely due to a recent increase in natural mortality. Most of the statistical evidence given herein supports the predation hypothesis as the most reasonable explanation for the recent rise in M and failure in weakfish productivity. Although results from regression and production models alone do not demonstrate causality, recent empirical evidence is consistent with a predation hypothesis involving striped bass. In addition, the apparent emergence of a weakfish recruitment bottleneck between ages 0 and 1 makes stock rebuilding via the implementation of additional management measures a difficult task.

We developed projections of weakfish stock biomass under a range of F levels, using an external production modeling approach that did not require an assumption of ecological stability. Z was considered to be the negative counterpart of the intrinsic rate parameter (r') and the Schaefer biomass dynamic model was reparameterized with the intrinsic rate of increase parameterized as (r' – Z) to project biomass into the future under current F levels, a 50% reduction and a complete moratorium. Results indicated that stock decline would continue even with a moratorium. However, continued current levels of F were projected to drive the stock to extinction within 10 years, while a 50% reduction would merely extend the time to extinction. A moratorium would eliminate extinction, but only a decline in M would allow stock rebuilding.

Part 2 of this assessment contains analyses that further examine the role of finfish predation and inter-specific competition on the recent rise in weakfish natural mortality. Several hypotheses

are offered to better interpret the intricate trophic pathways between weakfish and several candidate finfish species of importance in the mid-Atlantic region, including Atlantic menhaden, spot and bay anchovy, Atlantic croaker and striped bass. Our findings demonstrate that the potential impacts of predation and interspecific competition on weakfish and other exploited finfish stocks should be integrated into fisheries models and rigorously tested as a potential alternative explanation to the overfishing hypothesis.

## TERMS OF REFERENCE

1. Characterize commercial and recreational catch including landings and discards.

2. Review adequacy and uncertainty of fishery-independent and dependent indices of relative abundance.

3. Review the appropriateness of constant and variable natural mortality (M) estimates in the assessment.

4. Review the estimates of fishing mortality (F), spawning stock biomass, and total stock biomass for 1981-2004, and characterize the uncertainty of these estimates.

5. Review the estimated biological reference points, as appropriate.

6. Review stock projections.
    - Review the projection of impacts on the stock of recent estimated rise in fishing mortality.
    - Review the projection of stock response to reductions in fishing mortality given the estimated increase in natural mortality.

7. Make research recommendations for improving data collection and assessment.

## INTRODUCTION

The management unit for weakfish is the Atlantic Coast. The fisheries for weakfish were largely unregulated until the 1990s, although some states had their own regulations. Weakfish are subjected to estuarine and near-shore fisheries from a variety of gears as they moved into and out of their estuarine spawning grounds. The largest landings, however, have historically occurred in the North Carolina fisheries targeting the overwintering aggregations off the Carolina coast. The Atlantic States Marine Fisheries Commission developed a Fishery Management Plan in 1985, which was first amended in 1992, but these plans were not mandatory. In 1993, Delaware and New Jersey instituted some management measures prior to most other states, but coastwide management measures were not implemented until 1995 when Amendment 2 to the Weakfish Fishery Management Plan was implemented under a mandatory basis governed by the Atlantic Coastal Cooperative Fisheries Management Act. Amendment 4 was passed in 2002 and made some relatively minor changes to regulations.

Commercial management measures include a minimum size of 12" (certain gears in certain states excepted), minimum mesh sizes to achieve the minimum size limits and effort restrictions designed to achieve a 32% reduction in fishing mortality from a baseline time-period (1990-1992) representing an unregulated fishery. All states but North Carolina have seasonal closures. North Carolina has an area closure (waters south of Cape Hatteras) instead. The plan also mandated bycatch reduction devices for the South Atlantic shrimp fishery, which required testing to demonstrate a 40% reduction in bycatch by number or a 50% reduction in bycatch mortality.

For the recreational sector, Amendment 3 included a varied set of recreational minimum size and creel limit combinations designed to provide incentives for conservation, based on equivalency in the currency of spawning stock biomass. For example, current regulations allow a 6 fish creel limit if a state has a 12" minimum size, an 8 fish creel limit if the minimum size is 13" (33 cm), a 10 fish creel limit if the minimum size is 14" (35.6 cm), etc. Northerly areas of the range tend to have larger fish, on average. Whether these larger fish are simply the product of northern habitat, or are larger, older fish from southerly areas that migrate north in the summer is not clear. Minimum sizes in New York and southern New England are 16" (40.64 cm) for both recreational and commercial fisheries, while states to the south have 13" minimums for recreational and 12" minimums for commercial, although some states have varied their recreational regulations within the suite of options offered in the FMP.

Weakfish have historically waxed and waned, according to landings records. For example, Bigelow and Schroeder (1953) report that during the latter part of the eighteenth century they were "…well known in Massachusetts Bay. But they vanished so completely sometime prior to 1800 that when a stray specimen was taken at Provincetown in June 1838, it was sent to Boston for identification. In the second half of the 1800s, they again became abundant off southern Massachusetts by 1870. Around 1900, a significant fishery developed in the southern Gulf of Maine with landings of 45 mt, in which 2 kg weakfish were abundant. Bigelow and Schroeder stated that "This marked the commencement of a period of local abundance, which was entirely unexpected (for nothing like it had been experienced since the settlement of the country), and which (with its equally sudden eclipse) is perhaps the most interesting event in the history of the local fisheries…during the summer of 1903 that the traps at North Truro alone reported 280,000 pounds (116 mt)." In 1906, when landings had begun to decline, "…the Cape Cod Bay traps (excluding Barnstable, Chatham, Yarmouth and Dennis) reported almost half a million pounds for that year (208 mt). By 1910 only 907 pounds were reported from the Gulf of Maine. Weakfish were completely absent in most years since that time in landings reports from the Gulf through the period covered by their 1953 report. They discuss a hypothesis that "weakfish are plentiful when bluefish are scarce…"

Joseph (1972) reported that as of 1967, "…weakfish stocks have been at record lows for the past few years." All the states north of Cape Hatteras collectively landed only 416 metric tons in 1967, whereas the "all-time high catch" was 14,969 mt in 1945. In the 1970s and early 1980s, large catches and large weakfish were common. Catch-per-unit effort estimates from Virginia data showed a large peak in 1936, not in 1945. This analysis indicated that weakfish had been continuously declining from 1945 to 1967. Joseph also cites Perlmutter et al. (1956) who stated that prior to 1910 the bulk of the weakfish catch was obtained north of Chesapeake Bay and were predominantly fish aged 3 and older, but by the 1920s, Virginia was taking more than half the

total catch. Virginia, however, as today, "has always depended on smaller and younger fish. This means that in 1945 the number of weakfish captured may have been as much as twice the number caught in 1908 when the landings were approximately the same by weight." Joseph then raises the possibility that this shift to higher numbers of younger fish could have led to recruitment overfishing. He also reported that the abundance of weakfish larvae in ichthyoplankton tows in lower Chesapeake Bay in 1959-1963 was less than one per tow, whereas Pearson (1941) had collected 25-67 larvae per tow in 1929-1930. Joseph advanced a hypothesis that the decline in weakfish stocks was caused by the3 advent of widespread use of DDT beginning in 1945. It was used for mosquito control in salt marshes as well as for agriculture.

Several Mid-Atlantic states had thousands of weakfish per year entered in their recreational tournaments, where the minimum sizes were as high as 4.4 kg. In 1981, coastwide landings were 19,000 metric tons (Table 2). From 1982 through 1988, landings fluctuated from 10,000 to 14,000 tons. Landings declined beginning in 1989, reaching a nadir of 3600 tons in 1993 and 1994. Landings then climbed to a second peak during1982-1988, declined rapidly in the early 1990s, rebuilt slightly through 1998, and finally declined to an all-time low by 2003.

**Previous assessments**

The stock assessment of weakfish was last updated in 2002 (Kahn 2002b) with data through 2000. That report focused on results from tuned virtual population analysis using ADAPT. The Weakfish Stock Assessment Subcommittee had also in hand several alternative approaches that we were exploring, including a relative exploitation analysis (Crecco 2002), biomass dynamic model (Uphoff 2002a) and Integrated Catch at Age model (separable VPA: De Silva 2002). The ASMFC Weakfish Management Board, however, requested that we update the ADAPT model, since that had been used for the 1999 stock assessment, which had been approved by the Stock Assessment Review Committee meeting at the Northeast Fisheries Science Center in late 1999 (NEFSC 2000).

The 2002 assessment update had a serious problem with severe retrospective bias in the ADAPT results. This problem was uncovered by retrospective analysis, where the model was run with the most recent year of data removed; this was done repeatedly going back for several years. The estimates of fully-recruited fishing mortality and spawning stock biomass for a given year were then compared over the runs to see if they changed as additional years of data were included. While it has often been stated that the most recent year's estimates from VPA are the least certain, the retrospective analysis of the 2002 model showed that the uncertainty extended back for several years. A distinct pattern was apparent; as additional years of data were added, the estimate of F for a given recent year increased substantially. Conversely, estimated SSB declined by 50%. For example, when 1996 was the terminal year (all data after 1996 deleted), the estimate of fully recruited $F_{1996} = 0.17$. After the addition of four years of data through 2000, the estimate of $F_{1996}$ rose to 0.32, an 88% increase. The estimate of $SSB_{1996} = 40{,}379$ metric tons (mt) when 1996 was the terminal year. When data through 2000 was included, the estimate of $SSB_{1996}$ declined to 27,134 mt, which was a 33% decline. This bias extended back 7 years to the 1993 estimates. The estimated $SSB_{1993} = 12{,}164$ mt when 1996 was the terminal year. When data through 2000 was included, this estimate declined by 27% to 8,884 mt.

The assessment approved by the SARC had a similar retrospective bias which was discussed in the report (NEFSC 2000). Essentially the retrospective bias means that estimates of management parameters for recent years are unstable and hence unreliable. As part of the 2002 assessment process, Uphoff (2002b) presented a bias correction approach for the retrospective pattern, but such corrections are dependent on the assumption that the bias pattern in estimates of several years back will continue into the new terminal year estimates. Previous assessments had used untuned VPA, Cagean and Extended Survivors VPA. The 26th SARC reviewed an earlier assessment in 1998 but did not approve the catch at age modeling effort in that assessment. The 26th SARC recommended that ADAPT be used for the catch-at-age analysis.

**Review of work in progress by the 40th SARC**

The 40th SARC meeting in November 2004 reviewed the current assessment as a work in progress, after we made it clear that we did not have a completed assessment in November 2004. One of the SARC reviewers commented on development of the catch-at-age matrix after discussing the need to estimate catch at age from different states with different minimum sizes and from the recreational data obtained from NMFS that, "Because of the nature of this fishery, this is a complex undertaking." (Shelton 2004). The SARC agreed that "the current status of the assessment was insufficient as a basis for providing advice."(Cook undated). The SARC found there were conflicting signals from the research trawl surveys which tended to indicate higher abundance versus the catch or catch-based indices, which indicated declining abundance. The SARC recommended analysis of the various surveys and exclusion of any that are not internally consistent or that portray unrealistic variation or strong year-to-year variation. The SARC also recommended that the assessment proceed by stating various hypotheses about stock status with implied management action, then evaluating which evidence and analyses support the various hypotheses. This approach of exploring alternative hypotheses dealing with conflicting data is also recommended by Hilborn and Walters (1992, pp. 491, 536) and Schnute and Hilborn (1993).

A decision table for weakfish management lays out 3 basic hypotheses: stock increase, stock stability and stock decline (Table 1A). The table lays out potential likely stock responses for each hypothesis to three general management approaches: restricting harvest, status quo and liberalizing harvest. In general, in the case of stock decline, restriction would pose the best chance of reducing or stemming the decline. In the case of stock stability, status quo seemed reasonable, and in the case of stock increase, liberalization would be reasonable, although not required. In contrast, liberalization or status quo may increase the chance of further stock decline, if that hypothesis is correct. We attempt to summarize the evidence supporting each hypothesis in Table 1B.

## LIFE HISTORY

Weakfish are an important sciaenid species of the Atlantic coast with its primary range from North Carolina in the upper southeast through southern New England. It is also encountered south to Florida. Weakfish are primarily estuarine and inshore oceanic inhabitants who migrate seasonally. In the autumn, they migrate south to North Carolina or Virginia coastal waters, where they overwinter. In spring they move northward and inshore into estuarine spawning grounds including Pamlico Sound in North Carolina, Chesapeake and Delaware Bays and smaller coastal

estuaries up through Gardiners Bay on eastern Long Island, New York and as far north as Long Island Sound and Narragansett Bay in Rhode Island. The ASMFC Fisheries Management Plan considers weakfish to be a unit stock, based on genetic analysis (Graves et al. 1992). Recent work however, using geochemical composition of otoliths, found weakfish homed to their natal estuaries (Thorrold et al. 2001). This was the first published example of an estuarine spawner exhibiting homing behavior. Earlier tagging work performed in the 1930s also indicated that weakfish returned to their natal estuary (Nesbit 1954). These findings are not consistent with the unit stock hypotheses, and it should be pointed out that the genetic analysis cannot detect separate stocks if there is even a very minimal amount of mixing among stocks.

Surveys along the Atlantic coast indicate that estuaries provide feeding areas and spawning grounds for adult weakfish and are equally as important as nursery areas for juveniles. Adult weakfish are often found near the periphery of eelgrass beds, perhaps because weakfish feed on shrimp, other crustaceans, and small fish that are found near these grass beds. Spawning occurs in late May through the summer in the latitude of Delaware Bay and occurs inside the Bay. Spatial and temporal variation in juvenile weakfish diet has been observed in studies conducted in the Delaware Bay and Chesapeake Bay (Hartman and Brandt 1995, Grecay and Targett 1996, Latour et al. *in review*). In Delaware Bay, Grecay and Targett (1996) found mysid shrimp to dominate the diet of juvenile weakfish collected in 1986, while the bay anchovy dominated the diet of juvenile weakfish collected in the Chesapeake Bay in the early 1990s. Latour et al. (*in review*) examined the diet of weakfish from the Chesapeake Bay from 2002 to 2004 and found that mysid shrimp were an important component of the diet not only in juvenile weakfish but also for adults in contrast to earlier diet studies of Chesapeake Bay weakfish (Hartman and Brandt 1995). Part 2 of this report examines changes in reported weakfish diet in detail.

Older weakfish typically have been shown to become increasingly piscivorous with age, with Atlantic menhaden or other clupeids comprising a significant portion of the diet of older weakfish (Merriner 1975, Hartman and Brandt 1995). Recently, Latour et al. (*in review*) found mysids and bay anchovy to comprise a significant portion of the diet of all age weakfish in Chesapeake Bay, with Atlantic menhaden comprising only a small portion of the diet of age-5+ weakfish. Differences in the two studies were attributed to different sampling methods or temporal changes in the abundance of prey items between the time periods of the two studies. The low prevalence of other sciaenids, spot and croaker, in light of high commercial landings of those species was also noted (Latour et al. *in review*).

Maximum age recorded using otoliths was 17 years. The ASMFC Weakfish Technical Committee considers Tmax to be 12 years. World record weight is 7.75 kg. Growth rate has slowed since 1990, to the point that mean lengths at age of adults are several inches shorter than they were about 1990 (Lowerre-Barbieri et al. 1995, Kahn 2002a). Weakfish weight at age plummeted in the 1990s by nearly half for 3-5 year-old weakfish. Ninety per cent of weakfish are mature at age one. Weakfish are indeterminate batch spawners (Lowerre-Barbieri et al. 1996). The 26$^{th}$ SARC recommended that M = 0.25 be used in modeling constant natural mortality.

## FISHERY DESCRIPTION

Landings from 1950-2003 peaked in 1981 (Figure 1A). During the period from 1982-2004, landings were highest at the beginning, totaling about 12,500 metric tons in 1982. Landings declined in 1989 through 1993. An increase began in 1995, the year Amendment 2 was approved. Landings then peaked at above 5,000 metric tons in 1998. A decline began in 1999, which continued through 2004, which was a record low level of less than a thousand metric tons (Figure 1). Landings of weakfish by the commercial and recreational sectors have followed similar trends of strong declines in recent years (Table 2; Figures 1, 1A, and 2). This fact is strong evidence that the stock is declining. If recreational landings, for example, had declined at a much higher rate than commercial landings, we could suppose that recreational fishers had reduced efforts directed at weakfish, or that weakfish had changed behavior to make them less available to recreational anglers, specifically. Since landings by both sectors have declined in parallel, changes in directed effort or availability are much less likely reasons.

In the winter, overwintering aggregations off North Carolina are harvested by gill nets and fly net trawlers, and these landings are large enough that they cause North Carolina to exceed other states' commercial landings (Table 2). Other major states are Virginia and New Jersey. When weakfish move north and inshore into estuaries from Pamlico Sound, North Carolina through Narraganset Bay, Rhode Island, they are harvested by a variety of estuarine gears, including gill nets, pound nets and floating traps, seines and hand lines. When weakfish move south on the fall migration along the coast, the aggregations are targeted with trawls and gill nets. In 1999, for instance, gill nets caught the largest share of the commercial landings, 48%, while trawl landings were second at 27%, followed by pound nets at 20% and haul seine at 5% (Vaughan 2000).

Patterns in recreational total catch and harvest changed after imposition of minimum sizes and creel limits in 1995 (Figure 2a). After this time, total catch (A + B1 + B2 of the MRFSS) became significantly larger than harvest. This suggests that the regulations had a significant impact on recreational harvest, causing a large increase in live releases (discards).

There have been significant changes in reporting requirements for commercial landings in two major states, Virginia and North Carolina, during the period covered by this assessment, as well as a federal change. In 1993, Virginia implemented a commercial fishermen mandatory reporting system, whereby each harvester reports daily activity (harvest, effort) on a monthly basis. The previous system in Virginia had been a voluntary buyer-reporting system. North Carolina in 1994 mandated trip-level reporting by licensed dealers for all commercial landings. This program requires dealers to complete a trip ticket for each transaction with a fisherman. These reports must be submitted on a monthly basis to the North Carolina Division of Marine Fisheries (NCDMF). Previously, the state had a voluntary reporting system from 1978-1993 obtained through a NMFS/NCDMF cooperative statistics program. In addition, NMFS in 2004 implemented a mandatory electronic reporting system for all federally-permitted seafood buyers. The combined effect of these improvements in these reporting systems is a probable increase in accuracy in landings estimates.

North Carolina landings from four estuarine gears show declines over the period 1994-2003 (Figure 3a). Catch-per-unit effort indices of abundance from these gears suggest that the landings decline is from a decline in abundance, not a decline in effort (Figure 3b). Virginia estuarine pound net CPUE exhibits a similar decline. In contrast to the estuarine gears, CPUE of two

oceanic gears employed on the overwintering aggregations off North Carolina do not show a declining trend, although CPUE declined in the most recent years (Figure 3c). Because these gears target aggregations, such fisheries can maintain CPUE in the face of stock declines if fishers can locate remaining aggregations, particularly mobile gears such as fly net trawlers. Therefore, lack of a declining trend in these latter two indices should not be taken as indicative of stable abundance. In contrast, estuarine fisheries would usually be targeting weakfish in less aggregated distributions.

## INDICES OF RELATIVE ABUNDANCE

### Recreational catch per unit effort indices

Indices of relative abundance from recreational catch-per-unit effort were reinstated in this assessment. While tables of similar indices appeared in the last peer-reviewed assessment report (NEFSC 2000), the indices had not been used in the final run because the SARC advised that fishery dependent indices were less desirable than fishery independent indices. Problems have come to light with many of the available fishery independent indices during the course of this assessment (see below). An advantage of the recreational indices is that they have very broad geographic coverage, whereas most of the fishery independent indices are limited to the waters of one state. By using only part of the recreational fishery for the indices, the exact correspondence to the catch at age matrix is reduced.

We have developed a measure of effort that seems improved over previous estimates. Previously, the effort was termed directed effort, defined as trips that either caught weakfish or for which anglers stated n interviews that they were targeting weakfish. This approach has the danger of exhibiting hyperstability (Hilborn and Walters 1992), because as weakfish catches decline, the number of trips defined as directed will also decline. The resulting index tends to remain relatively high because the divisor (number of directed trips) falls off rapidly. Consequently, the index may not decline at the rate that abundance declines. Our new indices are based on either total catch or harvested catch per trip, where the trips are those that caught one of a suite of species that are significantly correlated with weakfish in anglers catches. If weakfish abundance declines, anglers will continue to fish for the co-occurring species. Consequently, the number of trips will not decline due to a decline in weakfish catches, and the indices are unlikely to exhibit hyperstability.

The indices are based on catches and trips in the private-rental boat mode in state waters in the Mid-Atlantic region. This component, while comprising a majority of the catch in the Mid-Atlantic region, which is the dominant region for recreational catch, is still only a portion of the total recreational catch. One index is the total catch per trip, including discards. Such discards are not aged, so this index is considered an age-aggregated index over ages 2 – 6+. We have also developed harvest-at-age indices which consist of the total recreational harvest (A + B1) of the private-rental boat mode in Mid-Atlantic state waters, divided by the total number of trips that caught one of the suite of co-occurring species. The total harvest was divided into harvest at age by multiplying it times the proportion at age of the total Atlantic coast recreational harvest per year.

Recreational indices of abundance show relatively high but erratic levels in the 1980s, a decline into the early 1990s, then some recovery into the mid-late 1990s, particularly by the total catch per trip. Following the imposition of recreational minimum size limits and bag limits in the early-mid 1990s, the total catch per trip began to increase and diverged from the total harvest per trip, presumably due to a change in selectivity caused by the new regulations. Selectivity of the harvest per trip age-structured indices presumably changed in the early-mid 1990s. After the increase of indices through about 1997, they leveled off and began to decline in 1997 to 2000, depending on the index (Figure 3e). Indices declined to very low levels by 2003. Figure 3d portrays harvested weight per trip. Fig 3e portrays the tuning indices used in ADAPT. Total harvest at age was lagged forward when used in ADAPT to tune abundance the following January 1. Total catch per trip, including discards was not lagged. A third set of recreational tuning indices was developed by Crecco (2005) and used to estimate relative abundance for relative F calculation (Figure 3f). These indices are from MRFSS data on private boas trips in the Mid-Atlantic, either total weight caught including discards (discard mean weight assumed equal to harvested mean weight) per trip, using total trips, or total number caught, including discards per trip.

**Research trawl surveys of relative abundance**

After the 30$^{th}$ SARC recommended that the weakfish assessment use only data from the core area of abundance (NEFSC 2000), defined as New York through North Carolina, the SAS pared down the number of age-structured surveys employed to four: the NMFS North East Fishery Science Center (NEFSC) fall inshore survey which has run continuously since 1975, the New Jersey Division of Fish, Game and Wildlife ocean trawl survey (NJ) conducted from 1989 through the present, the Delaware Division of Fish and Wildlife's 30 ft. trawl survey of Delaware Bay (DE) conducted intermittently from 1966 but used here from 1982-1984 and 1991-2003, and the South East Monitoring and Assessment Program (SEAMAP) conducted from 1989 through the present (Table 3). We also use six indices of age 0 abundance which we lag and tune to age 1 abundance that are conducted by the New York Department of Environmental Conservation in Peconic Bay, the Delaware Division of Fish and Wildlife's juvenile trawl survey in Delaware Bay, one conducted by the Maryland Department of Natural Resources in Chesapeake Bay and one conducted in the Maryland Coastal bays, one conducted by the Virginia Institute of Marine Sciences in the Chesapeake Bay and one conducted by the North Carolina Division of Marine Fisheries in Pamlico Sound. We also use a survey of 1 year old abundance conducted by the North Carolina Division of Marine Fisheries in Pamlico Sound that we lag and use to tune abundance estimates of age 2 (Table 4). Shelton in his report from the 40$^{th}$ SARC in 2004, stated that "a very important point in the context of the 2004 weakfish assessment" was made in Crecco's (2002) relative exploitation analysis using data through 2000, that "tuning indices that display high frequency fluctuations in relative abundance (large year effects) are likely prone to excessive measurement error, poor reliability and low information content about stock variability". Because of these concerns, we developed an objective screening and evaluation analysis for the four trawl surveys, namely catch curve estimation of year class total mortality. The criteria for inclusion was that a survey did not display negative Z, that is, that a survey not indicate that year classes grow in abundance throughout their life. In fact, year classes can only decline in number throughout their life.

Here we focus on the four age-structured surveys, as these have the major influence on abundance and F estimates for both the ADAPT model and the biomass dynamic model based on survey indices of relative abundance (Uphoff 2005a). The only survey that was conducted continuously from 1981-2003 is the NEFSC fall inshore survey. While this survey covers the region from Cape Cod to Cape Hatteras, the NEFSC has recently revised the weakfish index, using only tows inshore from New Jersey through Cape Hatteras. The mean total catch per tow and exploitable biomass per tow (Uphoff 2005a) from 1981-2003 peaked in 2003 (Figure 4). This peak in 2003 also appears in the indices for ages 1-3 (Figure 5). Due to lack of precision in fitting indices of older ages, the SAS uses only ages 1-4 of this survey. As part of the assessment, we used catch curve analysis to estimate the instantaneous total mortality for each year class appearing in each survey. The NEFSC survey Z estimates showed biologically impossible results, namely that total mortality was negative, indicating a year class gained members during its lifetime. Therefore, while we used this survey during our initiql ADAPT run to be comparable to the 2002 ADAPT run, we excluded it from further runs as biased and biologically implausible. The probable cause of this bias is large effects of year-to-year changes in availability of weakfish to the survey. This survey comes down the coast once in the fall. If it coincides with the fall migration of weakfish, catches are likely to be large, and vice versa. The migratory nature of weakfish produces serious difficulties for a coastal survey that is run once a year, such as the NEFSC survey.

The New Jersey coastal trawl survey index has exhibited saw-toothed fluctuations in recent years with no trend (Figure 6). The indices by age indicate that the relatively high 2004 value is primarily due to age 1, but age 3 and age 4 are relatively high also. When the survey indices were analyzed as year class catch curves, the survey had a recent year class, 2000, that showed negative Z, like the NEFSC survey. The 2000 year class had only 2 ages in the survey, ages 1 and 2, but they also show a positive slope. This survey then, in recent years, also exhibits estimates that are biologically impossible. On that basis, we eliminated the New Jersey survey from the second set of ADAPT runs.

Moving down the coast, the Delaware survey shows a different pattern than the NEFSC and the New Jersey surveys. The total catch per tow and the index of exploitable biomass peaked in 1996 and have generally declined since then, with some fluctuation (Figure 8). The indices by age have been high recently in age 1, followed by age 2 (Figure 9). Older ages have declined, however. In fact, age truncation is occurring in the indices: Age 6 declined to 0 in 2002 and 2003, while age 5 declined to 0 in 2003. This truncation is the reverse of the build-up of the age structure that occurred in the early 1990s. In 1991, the oldest age present was age 3. Older ages appeared gradually until Age 8 appeared in 1999. By 2001, though, the age structure began to truncate. Total mortality estimates by catch curve analysis found no year classes displaying negative Z in this survey (Table 3).The year class mortality estimates show a decline to a nadir for the 1993 year class, which was present from 1994-2000. Total instantaneous mortality then increased to levels of 1.5 or higher for the 1996-1999 year classes, declining slightly for the 2000 year class.

The final age-structured survey is the SEAMAP survey, from which we use tows along the North Carolina coast only. This survey's mean catch per tow increased to high levels in the 2003 and 2004 indices (lagged 2002 and 2003 fall indices). The age-structured indices for ages 1 and 2 are

the source of the increase in the last 2 years, with ages 3 and 4 showing very low and relatively flat values (Figure 9a). Ages 5 and 6 from this survey have been eliminated due to low precision, as for the NEFSC survey. Catch curve estimates of total instantaneous mortality from the SEAMAP survey found no instances of negative Z (Table 3). Since only 4 ages were available, little information about trends and precise estimates of Z can be obtained from this survey. Since all estimates of Z were positive, however, this index was judged to be biologically plausible to some extent and was included in the second cut of ADAPT runs.

## DEVELOPMENT OF CATCH-AT-AGE AND WEIGHT AT AGE MATRICES

Prior to the 1990s, most ageing of weakfish was based on scales. Otoliths were used increasingly in the 1990s. They were judged to be clearer to read. The Technical Committee conducted comparative studies using otoliths and scales from the same fish and determined that different age patterns of age structure were obtained with the otoliths versus scales. The committee decided to convert older scale-based ages to otolith equivalents, using a procedure akin to age-length keys. So for a given scale age, certain proportions were assigned to several otolith ages, based on scale-otolith data. For some years now, only otolith ages have been accepted.

The catch-at-age matrix for 2001-2003 was developed using the same general procedure outlined in Kahn (2002b). Four age-length keys were developed for each year, following the procedure used by Vaughan (2000), a north early (first six months), north late (second six months), south early and south late. All age-length data available from commercial samples or research surveys was pooled into these keys. Sample sizes are presented in Table 4. The overall number of samples per metric ton landed is higher for commercial than for recreational landings. The distribution of samples among regions, however, shows that the northern areas of the range have been deficient in sampling. Few commercial samples have been conducted north of Delaware. In recent years, Rhode Island has obtained length and some age samples from its floating trap fishery; these samples indicated a striking difference from the size structure of the more southerly landings (Figure 3d). In New York and southern New England, the minimum size for recreational or commercial harvest is 16” (40.6 cm), while New Jersey and south have minimum sizes of 13” (33 cm) for some New Jersey gears some of the year, or 12” (30.5 cm) for commercial catches in New Jersey’s other gears and all states south of New Jersey (Virginia and North Carolina have some estuarine gears with no minimum size for landings). No state south of New York has a 16” minimum size for recreational harvest, because many fish are caught below this size limit. The Rhode Island commercial length frequencies and the higher minimum sizes in the north indicate that northern areas tend to produce larger fish, whether due to migration of larger southern fish north or for some other reason. Consequently, substitution of southern length frequency distributions for northern commercial harvest may bias the estimated catch at age towards younger fish. While we truncated the lfds at the 16 inch minimum size for years 2000-2003, this procedure was not followed for previous years.

Recreational catch at age was developed as in Vaughan (2000), where for each year, early and late catches were divided into geographic regions, a north and south region. Therefore four length frequency distributions were obtained from the Marine Recreational Fishery Statistical Survey (MRFSS) for each year: north early, north late, south early and south late. The corresponding age-length keys were applied to each of the length frequency distributions to

convert length frequencies into proportions at age. These proportions at age were multiplied by the estimated total recreational losses. These losses were estimated as the MRFSS estimated total number harvested (A + B1) plus 20% of the estimated discard numbers (B2 portion of the MRFSS estimates). The Weakfish Technical Committee has in the past estimated recreational discards to undergo a mortality rate of 20%. Recent discussions have concluded that the committee may change this mortality rate estimate to 10% based on recent experimental results, but we have not implemented this change yet. Although discarded weakfish may tend to be smaller than harvested weakfish since 1995 due to imposition of minimum size limits, we currently have no data with which to estimate lengths of discarded weakfish. Consequently, we assume the discards have the same length distribution as harvested weakfish.

Commercial catch at age was developed by half year, state and gear due to different regulations among states and different size selectivity among gears. Gears employed fall into five main categories: trawl, gill net, pound net, haul seine and long haul seine and hook and line (handlines). Gears were sometimes combined or substituted, depending on availability or lack of sample data for a particular gear. For the north region, length data from Virginia, Delaware and Rhode Island were developed into gear-specific length frequency distributions for gill net, haul seine and pound net/floating trap gear. Maryland contributed trawl length samples for late 2003 and some pound net lengths. Virginia pound net data was used for trawl length frequency distributions in many states, due to severe lack of sample data from trawl landings. Some trawl length frequency distributions were obtained from the NMFS At-Sea Observer database. MRFSS recreational length frequency distributions were used to estimate commercial hook and line catch lengths. For New Jersey and New York catches, Virginia, Delaware and Rhode Island length frequencies by gear were used, but we truncated them to account for 16 inch minimum size limits in New York and the 13 inch minimum size for portions of the New Jersey landings. Catch at age matrices were developed for each gear in each state (where applicable) for each half of the three years 2001-2003.

To allocate landings among lengths, lengths were converted to weight using a length-weight equation for each half-year, developed from length-weight data supplied by the states (H. Rickabaugh, MD DNR personal communication). The frequencies at length then became the frequencies for each mean weight. Frequencies at weight were then converted to proportions at each length-weight combination. The total landings in pounds for a gear-state-season were multiplied by these proportions to give the landings in pounds at each length-weight combination. Landings at each length were then divided by the mean weight at that length to convert from pounds into numbers of fish at length, giving catch at length in numbers. The catch at length was then converted into the catch at age by means of an age-length key.

For the first time, the catch at age matrix included estimates of commercial discards (de Silva 2004). The Subcommittee learned that data on weakfish discards was included in some of the NMFS at sea observer data, which began in 1994. These data were developed into several different matrices of estimated discards using different methods and assumptions. The primary gear that produced weakfish discards was trawl gear. Smaller numbers of discards were produced by gill net. Small sample sizes and spotty coverage in many years made estimation tenuous in many cases. After due consideration, the committee chose a method that scales up the ratio of discards to harvest of a reduced core suite of target species. That is, the ratio of at sea

observations of the number of discarded weakfish to pounds of harvested target species by gear (trawl and gill net) was scaled up to total discard estimates based on total landings of the target species. For example, if 50 weakfish were discarded per 1000 pounds of bluefish landed by trawl gear, we would get the total coastwide landings of bluefish by trawl gear, divide those landings by 1000, and multiply the quotient by 50 to estimate the total number of weakfish discards due to bluefish harvest with trawl gear for that year. For trawl gear, the most common target species were summer flounder, Atlantic longfin squid, horseshoe crabs, butterfish, bluefish and weakfish. For gillnet catches, the most common target species harvested with weakfish discards were weakfish, bluefish, Atlantic croaker, butterfish, spot, Atlantic menhaden and spiny dogfish. For a full explanation of the procedures used and problems encountered, see de Silva (2004). The primary reason for discarding weakfish in most years was regulations; the second most common reason was market conditions. For 1998-2000, however, market conditions were the most common reason for discarding weakfish.

We also explored an alternative to the ratio approach, which was a regression approach; however, it produced poorer estimates than the ratio method. We also explored an alternative to scaling up observed discards by total target species landings. This alternative is estimating discards per trip and scaling up to total discards by the total number of trips. Unfortunately, commercial trip data was not available for much of the range of weakfish.

One pitfall with our approach is the possibility of overcounting discards. For example, if weakfish discards occurred on a trip that harvested croaker and bluefish, we did not want to scale up these discards by both the bluefish landings and the croaker landings, for that would be double counting. We used a reduced suite of target species to avoid overcounting of discards. A principal components analysis determined species associations among the target species. That is, the analysis determined which groups of species were often harvested together (on the same trip). Then we could scale up the observed discards per unit harvest for one species from each group to avoid overcounting discards. We thus selected a reduced suite of core species by selecting only one target species from each association. For trawl gear, four target species groups were identified: 1) Atlantic long-fin squid, 2) butterfish, 3) weakfish, Atlantic croaker and bluefish and 4) summer flounder. For gill net, four groups were also identified: 1) Atlantic menhaden and weakfish 2) Atlantic croaker and butterfish 3) spiny dogfish and 4) bluefish and spot.

Since the observer database does not cover years prior to 1994, estimated discards were hindcast, assuming that regulatory discards only occurred after imposition of regulations in the early 1990s. That is, the proportion of discards that occurred in the database for market reasons was assumed to be occurring back to 1982. Thus estimated discards were lower prior to 1994. Completed commercial discards at age are most commonly ages 0, 1 and 2 (Table 4, from Table 47 of de Silva (2004)). Since the VPA does not analyze catches of age 0, the addition of commercial discards to the catch at age tends to primarily increase the catch of ages 1 and 2. Figure 10 shows the catch at age estimate for 2002 with and without commercial discards as an example.

The total catch at age matrix including recreational and commercial landings and discards is in Table 5. Because commercial discard data was only available through 2002, we averaged the commercial discard estimates for 2001 and 2002 and used these for 2003.

For our update of the input data from 2001-2003, the estimates of the catch weights at age were developed using the process suggested by Quinn and Deriso (1999, p. 305) for unbiased estimates, employing the age-length keys and an average weight-at-age that is weighted by the frequencies at length within ages. This involved constructing spreadsheets for every component of the catch that we had developed catch at age matrices for, namely semi-annually for each significant gear in each of the nine states with commercial landings, plus 4 recreational catch at age matrices per year. For the 3 years we updated, the total number of spreadsheets developed exceeded two hundred. The report of the 30$^{th}$ SARC (NEFSC 2000) listed the following suggestion as a research recommendation: "Obtain mean weights at age corresponding to the catch-weighted mean weight from the catch at age estimation process." Previously, catch weights at age had been estimated with a von Bertalanffy model using all available age-length data, assuming catch occurred in the middle of the year. The problem with the old procedure is that it failed to take selectivity of the gear into account. It appears that we have fulfilled this SARC recommendation.

Catch weights at age for recent years showed a geographical trend, especially for younger ages. Mean weights at age tended to be larger in northern states (Figures 11-13). This could be due to higher minimum sizes in more northerly states, in part. The stock weights at age, or January 1 biomass weight at age, in contrast to the catch mean weight at age, is intended to depict the mean weight at age of the total stock, without fishery selectivity effects. The trend in these mean weights has been higher levels in the 1980s, when estimates are based on scale ages, and low points about 1995-1998, with recent increases (Figure 14).

On a related note, the 30$^{th}$ SARC report also made a research recommendation to "Investigate source of the relatively large sum of products correction factor." It is unclear exactly what this refers to, but it may have referred to the product of the estimated catch at age and the estimated mean catch weight at age. The sum over ages of this product should match the total landings. There does not appear to be a large discrepancy currently except for two years in the 1980s (Figure 15).

## CATCH-AT-AGE ANALYSIS

### Cohort catch curves

The most basic analysis of the catch at age matrix consisted of catch curves by year class or cohort catch curves. The cohort approach avoids violations of the assumption of constant recruitment that occur when catch curve analysis is performed across the catches at age of one year (Ricker 1975). The standard methodology was followed, where the log of the catch at each age was plotted, and analysis included all ages to the right of the modal age (Table 6; B. Murphy, RI DMF personal communication). Figure 16 plots the resulting estimates of total instantaneous mortality, Z, and estimates of F based on the assumption that M = 0.25, which the Weakfish Technical Committee has assumed in the past. Since the Z and F estimates are for the lifespan of

a cohort, they are not values that apply to only one year, as in a VPA. Rather, they estimate mortality over the range of years analyzed, as stated in Table 6. The general pattern is that year classes of the 1980s had relatively high Z estimates, fluctuating around 0.8. A nadir was reached with the year classes of the early 1990s, where Z for the 1992 year class was 0.3. This year class would have reached age 3 when Amendment 2 took effect in April 1995. However, Z climbed abruptly for the 1994 year class and reached a plateau for the remaining cohorts, fluctuating without trend from 1.3 to 1.5. The general trend of Z estimates here is supported by a significant correlation with year class Z estimates from an independent source, the catch curve analysis of the Delaware trawl survey (Figure 17). If we assume M = 0.25, F would be 1.05 to 1.25. However, these F levels are not supported by other analyses. The fishery regulations were relatively stable during this whole period. This suggests that the increase in Z indicated here could have been due to an increase in M, rather than an increase in F in the late 1990s and early 2000s.

**Gulland's cohort analysis**

The catch at age matrix was subjected to a Gulland cohort analysis (Haddon 2001), which is essentially an untuned virtual population analysis. This can be seen as an analysis of the catch data. Because the analysis proceeds from the most recent years and moves backwards, the most recent years' estimates are least reliable, since it assumes that the ages in the most recent year have no survivors. Therefore, the last three to four years' estimates should not be considered reliable. Starting four or five years back, prior to 2000, however, the estimates have more validity. As opposed to catch curves, cohort analysis gives estimates of F at age and year, assuming M = 0.25 (Table 7), and estimates of stock size (Table 8, Figure 18).

We consider 1999 to be the most recent year of reliable estimates. Figure 18 indicates that stock size was relatively high in the early and mid-1980s, peaking in 1986 at about 120 million fish. The stock then declined to about 50 million from 1989 – 1992. The stock began to increase in 1993, reached a recent peak in 1994-1996 at about 75 million, then declined to about 30 million in 1999. If we assume M was constant at 0.25, fully-recruited F estimates (ages 4 and 5) are erratic in the 1980s, fluctuating greatly between 1.0 and 2.5. From 1989 through 1993, F estimates are more stable, ranging between about 1.50 and 1.80. The estimate of F declines in 1994 and 1995, to about 0.75 in 1993 and fluctuated between 0.75 and 1.00 without trend until 1999. The pattern of average Z for ages 1-5 is also plotted in Figure 18. This estimate fluctuates erratically from 1982-1988, then stabilizes from 1989 – 1993 at about 1.25. Estimated Z declines in 1994 and 1995, and then fluctuates around 0.75 through 1999. This decline from 1995-1999 seems consistent with a reduction in F due to implementation of Amendment 2, in April 1995. The increased Z estimates for the 1995-1998 year classes seen in the two catch curve analyses (Delaware survey and catch at age matrix) are not detectable here, but no reliable estimates of Z are available after 1999 from the cohort analysis, which covers much of the relevant period for the later year classes in the catch curve analysis.

The estimates of fully-recruited F for the period since Amendment 3 was passed are considerably higher than some other estimates, fluctuating between 0.75 and 1.00. Most of the shifts in F and Z seem consistent with changes in fishery management. During the period of the unrestrained fishery in the 1980s and early 1990s, F and Z estimates were high. Some states, primarily New

Jersey and Delaware, imposed restrictions beginning in the early 1990s. Amendment 2, passed in July 1994, went into full force in April 1995.

**ADAPT results**

ADAPT was employed to analyze the catch at age data, in conjunction with survey and fishery dependent indices of relative abundance to tune terminal year estimates (actually, ADAPT estimates abundance in the terminal year + 1 and F in the terminal year). The first ADAPT run presented here, run 24, is an update of the model configuration recommended by the 30$^{th}$ SARC and implemented in the 2002 update (Kahn 2002b). Run 24 differs from the earlier models in that it includes estimated commercial discards in the catch-at-age matrix, but it uses the same set of tuning indices: all four age-structured surveys discussed above, plus age 1 indices from New York, Delaware, Maryland (2 such surveys), Virginia (VIMS survey) and North Carolina (Table 12), plus an age 2 survey from North Carolina. The run results (Table 9A) showed strong retrospective bias, similar to those of earlier years, and as such, is not considered reliable for recent years. The retrospective pattern is that F is underestimated (Figure 19, Table 9B) and spawning stock biomass is overestimated (Figure 20, Table 9B). When only data through 1998 is entered the fully-recruited F estimate for the terminal year, 1998, was 0.14. Once five additional years of data were input through 2003, the 1998 F estimate rose by 207% to 0.43. Conversely, the 1998 SSB estimate declined by more than half from 59,102 MT with 1998 data to 22,599 MT with 2003 data. With this amount of bias, the results of the VPA do not appear to be reliable after the early 1990s. The estimated F in 1991 increases by only 2.5% with the addition of 5 years of data, while estimated SSB for 1991 declined by 3%. Basically, in this run, the survey tuning indices indicate the stock is relatively high, so the estimated stock size in the terminal year +1, 2004, is estimated as a high number, 206 million (Table 9A). The stock size is then back-calculated to the terminal year, 2003, assuming M = 0.25 and adding in the catch. Since the catch was low and estimated losses due to natural mortality are moderate, the estimated stock size in 2003 is not much bigger than that of 2004. That result indicates total mortality was low, so when Z was estimated, it is relatively low. The assumed constant value of M = 0.25 was subtracted from that low Z and F is then estimated as extremely low, only .012 for age 4 in 2003, for instance. The combination of a high estimate of stock size in 2004 due to the survey indices, the low catch in 2003, and the assumption that M = 0.25 produce high terminal year estimates of stock size and F.

The 40th SARC panel that reviewed this assessment as work in progress agreed that the combination of high survey indices and low catches produced inflated estimates of N and low estimates of F. The reviewers indicated that the conflict between the high trawl indices and the low catch produced the retrospective bias observed. They were critical of some survey indices, particularly the NEFSC indices. They recommended critical review and removal of surveys that did not give biologically plausible results. Following their review, we conducted the catch curve analysis of the surveys described above and eliminated the NEFSC and NJ surveys on the grounds that they showed negative mortality, or “spontaneous generation” (growth of a year class in numbers during its life, as opposed to constant decline in numbers). The next run, run 14, used only the two remaining age-structured surveys, the Delaware and SEAMAP (Figures 21, 22, Table 9A). This model run showed a more severe retrospective pattern than run 24, however, with the terminal year F estimate with data through 1998 ($F_{1998}$ = 0.08), increasing by 450% with

the addition of five years of data to 0.44 (Table 9B). The estimated SSB for 1998 declined by 77% from the run with 1998 as the terminal year to the run with 2003 as the terminal year. Again, this indicates that F is probably greatly underestimated for recent years in run 14 and SSB is probably greatly overestimated.

Our next change was to include fishery-dependent indices of abundance as tuning indices. The Weakfish SAS had used recreational catch at age per unit effort as tuning indices in VPA prior to the 30th SARC. That committee recommended against using any fishery-dependent indices "because the SARC believed sufficient fishery-independent surveys were available" (NMFS 2000). However, we added recreational CPUE indices because the surveys did not give the model tuning information for estimation of terminal year abundance consistent with the fishery experience of drastically declining catches, except for some aspects of the Delaware survey. The 40th SARC agreed with this decision. These recreational CPUE indices are declining over the last several years.

Run 18 used the Delaware and SEAMAP age-structured indices and the age 1 and 2 tuning indices included in runs 24 and 13, plus recreational fishery harvest per trip for ages 3-6 (Table 9A). Since harvest changed due to minimum size and bag limits over the time series, we also added the unaged total recreational catch per trip (including discards – B2 component of MRFSS) as an aggregated index tuned to ages 2-6. The retrospective pattern in F and SSB of run 18 is similar to the previous two runs (Figures 23A, B), except that the final estimate of SSB for 1998 was approximately 2/3 of the final 1998 estimate of the two previous runs (Table 9B). Conversely, the final F estimate for 1998 was 50% higher than the estimates from the previous two runs. Not until we look back at the 1992 estimates have the estimates of F and SSB closely converged among these three runs, although they become roughly similar by 1995.

The DEDFW survey has a distinctive residual pattern in Run 18, however (Figure 24A). This survey had negative residuals in the early 1980s for younger ages, consistent with statements in reports from that period that recruitment was low. The survey resumption in 1990 began with negative residuals, followed by consistently positive residuals in the mid-1990s followed by negative residuals in recent years. The SEAMAP survey residuals are fairly random, but positive in 2003 and 2004 (Figure 24B). Recruitment indices residual patterns are consistent with a change in fishery selectivity around 1995 when mandatory compliance was instituted under Amendment 2. Residuals were largely negative prior to 1995 and then became positive, with several again becoming negative by 2002 (Figure 24C). The opposite pattern occurs with the recreational CPUE residuals (Figure 24D). In this case, residuals of the age-structured harvest per trip indices switched from positive to negative in 1995. This is consistent with a regulation-driven change in recreational selectivity, as minimum sizes and creel limits caused an increase in discarding, changing the catchability of the recreational fishery and consequently of these indices. Large negative residuals occurred for theses indices for ages 4 and 5 in 2004. The exception to the general pattern is the total catch index pooled over ages (Figure 24D). That index has a fairly random pattern, as would be expected since total catch (including discards) should not be affected by creel and size limits.

Run 18 has considerably higher F estimates and lower SSB estimates than runs 13 and 24, such that the SSB estimates for 1999-2001 are below the biomass threshold in Amendment 4 of

14,421 MT. However, the estimated SSB for 2002 and 2003 increased to 23,567 MT by 2003 (Figure 23B, 2003 data). Again, however, this estimate is biased high and presumably will decrease substantially with additional data. The estimated F for 1996-2000 is much higher in run 18 than in runs 13 and 24. In the former, the F estimates range from 0.50 in 1996 up to 0.75 in 2000. In the latter two runs, these estimates range from about 0.3 up to 0.44. The estimated F for 1995 is almost always lower than that of 1996-2000. For run 18, $F_{1995} = 0.31$, while for run 14, $F_{1995} = 0.28$. That year saw the mandatory implementation of Amendment 2.

Run 20 is the final ADAPT run presented here. It used only the recreational CPUE indices for tuning of aged 2-6 as described for run 18 (Table 9A). This completed a combination of runs with all survey indices (run 24), a reduced group of trawl survey indices screened for biological plausibility (Run 14), a run with these two surveys plus the recreational CPUE indices (run 18) and the recreational CPUE indices alone (run 20. No index tuned the estimate of age 1. Run 20 also shows a strong retrospective bias, but in the opposite direction from the other runs (Figures 25, 26, Table 9B). This pattern is reversed for estimates when data through 2002 only is entered. Here F is overestimated in recent years and SSB is underestimated. When 1998 is the terminal year, $F_{1998} = 2.05$, but with data through 2003, it declined to 0.70, for a 66% decline. The estimate of SSB when 1998 is the terminal year was only 5,468 mt, but it increased to 12,674 with the addition of data through 2003. Again, by about 1993, the estimates have converged to rough similarity with those previous runs. Distinct patterns appear in the residuals for this run (Figure 26B). For the age-structured harvest-per-trip indices, initially residuals were positive. They became mostly negative in the early 1990s and remained so until 2002, when ages 3 and 4 became positive, followed in 2003 by ages 5 and 6. Large negative residuals did not appear in this run, with none exceeding an absolute value of 2.0. The residuals for the total catch including discards (ages 2:6) were negative from 1989-1997 and positive from 1998-2003. Some of these residual patterns are clearly related to the change in selectivity in the middle 1990s, but this relationship is not as clear-cut as in Run 18.

The reason that the choice of tuning indices affects the estimates back approximately 10 years to 1993 has to do with the way ADAPT calculates the F on the oldest true age. Because ages 6 and older are pooled into the so-called "plus group", age 5 is termed the oldest true age in these analyses. VPA calculations move backwards through each cohort or year class, from more recent years when each cohort was older towards years farther back when each cohort was younger. In the case of the oldest true age, however, it is not correct to back calculate from a plus group, here age 6, to the oldest true age, here age 5. That is because the plus group contains members of more than one cohort, and to back calculate from plus group to oldest true age would inflate the age 5 numbers. Consequently, ADAPT uses the F estimate from the other fully-recruited ages as the F estimate for the oldest true age. In this case, we have only one other fully recruited age, age 4. Because we have only two fully recruited ages, either option in ADAPT to calculate this F on the oldest true, the average method and the Heincke method, arrive at the same number. So the F calculated for the cohort that is age 4 in a given year is used as the estimate of age 5 F, which age belongs to the previous cohort. This F estimate is used to calculate the abundance of age 5 with the catch data and catch equation (Anonymous 2003), $N = ZC/FA$, where A is total annual mortality as a percentage. Here Z is estimated assuming $M = 0.25$, so $F + 0.25 = Z$. Now that the abundance of the oldest true age in that year has been determined, the program back calculates the abundance of the same cohort in the previous year as age 4. The F estimated for age 4 is used

for the oldest true age of the previous cohort. Consequently, the effect of the tuned estimate of N in year T + 1 and F in year T propagates backward through a whole series of cohorts, in this case for about a total of 10 years.

The net result of the ADAPT models is that we have stable estimates from 1982 through about 1992 or 1993. More recent years have unstable estimates of fishing mortality and SSB which change dramatically as additional data is added. In previous assessments, this pattern was noted and discussed, but perhaps not emphasized as it should have been. For management purposes, we consider ADAPT results unreliable for parameters and trends after 1993. The estimates of F from 1982 through 1991 have proved useful, however. Crecco (2005) used them to scale relative F estimates to absolute F estimates. A cautionary note here is that the fact that the 1982-1993 estimates are stable does not necessarily mean they are accurate. Simulation work by Sinclair et al. (1991) found that the stable, converged estimates of VPA were not always accurate estimates. Since they created simulated data, they knew the correct estimates. In our case, we do not have that luxury. The combination of scanty data in the 1980s, even compared with more recent years, and the conversion of scale ages to otolith ages indicates considerable uncertainty in the estimated catch at age matrix during that decade.

In terms of the three biological hypotheses presented above, which are supported by the catch at age analyses presented above? Unfortunately, the ADAPT models are unhelpful in discerning recent stock trends. The catch curves by year class indicate that total mortality declined greatly for cohorts originating in the early 1990s, but then climbed up to high levels of about 1.4 since the 1995 year class (Figure 16). This estimate is a 75% increase over the Z estimates from the early 1980s. These estimates are averaged, essentially, over all ages in a year class, so they tend to be quite lower than the fully-recruited F estimates from VPA for the 1980s. The total mortality of 1.4 indicates that either fishing or natural sources of mortality have greatly increased in the later 1990s and early 2000s. This level of Z could produce stock decline and could be considered to support that hypothesis.. These estimates are supported by the independent Z estimation from the catch curves developed from the Delaware survey indices, and that considerably strengthens the case for a recent large increase in total mortality (Figure 17). The cohort analysis assumes that instantaneous natural mortality is constant at 0.25. Given that assumption however, the estimated stock size through 1999 declines steeply from the 1994-1996 plateau (Figure 18). Although that is not very recent, it is consistent with a stock decline at least over the period 1997-1999. The estimated decline occurred despite the fact that the estimate of F declined significantly after 1994. The stock decline depicted, then, does not seem to be caused by an increase in F.

## SIZE AND AGE STRUCTURE ANALYSIS

Amendment 4 requires that descriptors of age or size structure be reported to the Management Board as part of each stock assessment. Proportional stock density (PSD) is a standardized method for analyzing length-frequency data that quantifies size structure into categories of sizes of interest to recreational anglers (Uphoff 2005b). The Quality+ PSD (PSD Q+) equaled the proportion of weakfish greater than or equal to 210 mm (8.3 inches) that were 340 mm (13.4 inches) or larger in DE, NJ, and NEFSC trawl surveys. Sample sizes in the DE and NJ surveys

were large enough for precise estimates of PSD Q+, but sample sizes in the NEFSC survey were not and these data were excluded from analysis.

The PSD Q+ size quality indices for NJ (1989-2003) and DE (1966-1971, 1979-1984, and 1990-2003) indicated that size quality of weakfish in recent years was quite poor (Figure 27). A recovery in size quality after Amendment 3 (1996) faltered after 1998. Weakfish PSD Q+ has the potential to be a good bit higher than the peak observed in 1998. Values in the early 1980s were twice as high as this peak.

The DE PSD Q+ index was significantly and positively associated with recreational fishing quality (trophy citations) over a broad (DE, MD, VA) area, commercial and recreational yield along the Atlantic Coast, recreational harvest per trip in the mid-Atlantic (VA-NY), and the proportion of recreational harvest outside of 3 miles. Proportion of recreational harvest in bays and sounds was negatively associated with DE PSD Q+. These associations indicated that this size quality index was a highly relevant measure of population and fishery status that should meet the needs of the Weakfish Management Board. This analysis of size structure of the weakfish stock seems to be consistent with a stock in decline.

Our analysis of age structure assumes that the percentages at age from ADAPT output are not affected by retrospective bias. This assumption seems reasonable based on retrospective analysis of the 2002 ADAPT output (Kahn 2002). The mean bias for age 1, age 2, and age 3 weakfish in that final run was 0.88 for age 1, 0.83 for age 2, and 0.85 for age 3. Results of the current Run 20, the run preferred by the Technical Committee, show there has been a steep decline in the percentage of older weakfish since 1999 in all three runs (Figure 27a). Older weakfish comprised 5-8% of the estimated population during 1999 and this percentage fell to about 1% by 2003. Clearly, age structure is contracting rather than expanding toward "that necessary for restoration of the fishery".

## BIOMASS DYNAMIC MODELING

Biomass dynamic models (also known as surplus production models) are the simplest analytical methods that provide a full stock assessment (Haddon 2001). They are relatively simple to apply because they pool the overall effects of growth, mortality, and recruitment into a single production function. Their data needs are small - minimum data needed are an index of relative abundance and landings (both in weight). The stock is considered as undifferentiated biomass and age, size, and sex structure are ignored (Haddon 2001). Hilborn and Walters (1992) stated that if both methods are applied and give different answers, then assessment scientists should try to understand why the answers are different and analyze their management implications. This biomass dynamic model has been developed to supplement and corroborate the age-structured techniques employed elsewhere in the assessment.

Trawl survey indices of relative abundance were formulated as kg per tow (Figure 28; Uphoff 2005a). These indices were also employed to estimate relative F, where harvest in MT was divided by the average of the indices for that year plus the following year. The index is then harvest as a proportion of average biomass for a year and is more similar to F than to exploitation. These estimates indicate that F reached a peak in 1987, then declined gradually to a

low level in the mid 1990s (Figure 9c). A small rise in relative F occurred in some of the estimates in 1997-1998, then levels were very low through 2003.

The time-series fitting method was used to estimate production model parameters (Hilborn and Walters 1992; Haddon 2001). We used a spreadsheet version of the discrete form of the biomass dynamic model based on the logistic function:

$$U_t = U_{t-1} + rU_{t-1} (1-(U_{t-1} / sK)) - sC_{t-1} + \varepsilon;$$

where $U_t$ was the index of abundance in year t; $U_{t-1}$ = index of abundance the previous year, r = intrinsic rate of population increase; s = scalar for the abundance index; K = maximum population biomass; $C_{t-1}$ = harvest (commercial and recreational) in the previous year; and ε is measurement error (Hilborn and Walters 1992). A genetic algorithm super solver (Evolver, Palisade Corporation) was used to estimate parameters that minimized observation error ε (observed $\log_e U_t$ - predicted $\log_e U_t)^2$ (Prager 1994). The spreadsheet version of the model combined with the genetic algorithm provided a great deal of flexibility for trying different model variations.

Biomass of the exploitable stock in year ($EB_t$) was estimated as predicted $U_t$ / s (Hilborn and Walters 1992). Instantaneous annual fishing mortality rate in year t was estimated as

$$F_t = C_t / [(EB_t + EB_{t-1}) / 2] \text{ (Ricker 1975);}$$

$F_t$ in 2003 was approximated as $C_t$ / $EB_t$ (Haddon 2001). Relative biomass was calculated for sensitivity analyses as $EB_t$ / $B_{msy}$ in some cases or $EB_t$ / K in others; relative F was estimated equivalently.

Residuals were examined for normality and serial trends. Bootstrapping (Efron and Gong 1983) and jackknifing ("inflated" jackknife; Efron and Tibshirani 1993) sample reuse techniques were used to describe variability of parameters in the preferred run.

Several deterministic approaches were used to investigate sensitivity of preferred model parameters (r, K, s, and $U_0$) and estimates of F and EB. Discard estimates (recreational and commercial; de Silva 2004) were included in one run. Deterministic runs were made to test sensitivity of the preferred trawl survey based model to z-transformation (untransformed indices were modeled), aggregation of indices (mean z+1), addition or omission of discards, and omission of each z-transformed survey index time-series. An extended z+1 transformed trawl survey time-series (1975-2003) was created and compared to the base time-series. Delaware survey data were also split into long (1981-2003) and short (1990-2003) time-series, reflecting survey vessel changes (Michels and Greco 2003) and one DE model was developed with scalars for 1981-1989 and 1990-2003. Production model parameters r and K, and relative F (F/r) and relative biomass (EB/K) time-series were calculated for each model. Time-series sensitivity was explored by sequentially removing time-blocks of up to five years from the end of the time-series and up to seven years from the beginning.

All three time-series of z-transformed + 1 biomass indices generally agreed that EB was low during 1985-1993, and likely rising during 1994-1996 (Figure 28); EB indices were mixed from low to high during 1981-1984. Trawl survey EB z+1 indices indicated the stock slowly declined through the early 1990s and then underwent rapid growth in the mid-1990s. In any given year after 1996, trawl indices would lie between lows observed during 1981-1991 and values more

than four-times that level (Figure 28). Trawl based indices were positively correlated with each other. Correlations of EBNJ with EBFSC (Pearson correlation coefficient or $\rho = 0.69$) and EBDE with EBNJ ($\rho = 0.78$) were strongest and both were significant at $P < 0.005$. EBDE and EBFSC were not as strongly correlated ($\rho = 0.45$, $P = 0.054$).

The fit of the preferred run was modest ($r^2 = 0.42$; Figure 28). The overall mean of residuals was near zero (-0.09); residuals were positively skewed with a negative tail. EBFSC (N = 23) contributed 46% to total SSQ; EBNJ (N = 15), 31%; and EBDE (N = 18), 23%. A sequential trend was not apparent in the residuals as a whole. Residuals of EBFSC tended to be slightly positive overall (mean = 0.06) while residuals of EBNJ and EBDE tended to be negative (means = -0.23 and –0.17, respectively).

The intrinsic rate parameter (r) equaled 1.32 and K was estimated at about 41,000 mt; EB index in 1981 was estimated as 0.98 and the scalar was $4.932 \bullet 10^{-5}$. Precision of all bootstrapped (N = 200) parameters was excellent and estimates were not noticeably different between bootstrapped and jackknifed estimates.

Estimates of EB fell from 20,000 mt to 5,000 mt during 1981-1990, steadily climbed to 37,000 mt by 1997 and then leveled off between 37,000 and 39,000 mt (Figure 29). When changes in biomass were slight (1981-1990 and after 1996), bootstrapped estimates were very precise. Modest variation in estimates was observed when growth in biomass was rapid (1990-1996). Estimates of biomass have been very close to K since 1997 (Figure 29).

Estimates of F were near or exceeding the level that would have collapsed the stock ($F_{collapse} = r = 1.32$) during 1981-1991 (Figure 29). A rapid drop in estimated F followed and F was 0.17 by 1994. Estimates of F fell between 0.11 and 0.17 during 1994-2000 and F was all but extinguished by 2003 (F = 0.03; Figure 29). Trends in precision of F were the same as those for biomass; there was virtually no variation when changes were gradual, with some variation evident when transition was rapid.

The addition of discard estimates did little to change estimates in the directed harvest model (Figure 29). Parameter r rose slightly to 1.35, K fell to 39,910 mt, s increased slightly to $5.848 \bullet 10^{-5}$, and $U_{1981}$ increased to 1.45. Estimates of EB were slightly lower and F estimates were slightly higher when discards were included (Figure 29).

Twelve additional trawl survey based biomass dynamic models were developed for the 1981-2003 time-series, as was one extended time-series (1975-2003) model (Table 9C). Generally, the z+1 transformation resulted in stable parameter estimates in their eight scenarios; r ranged between 1.10-1.44 and K fell between 36,000 and 47,000 mt. Removal of each time-series of z+1 transformed surveys did not affect parameter estimates appreciably. Extending the three z+1 index time-series to 1975 resulted in a large drop in r (to 0.33), while K remained within the range of the estimates made with the shorter z+1 time-series. Biomass dynamic models using untransformed indices individually produced lower and more variable estimates of r (0.33-1.12) and higher estimates of K (some very much higher). DE survey models were very sensitive to length of time-series and whether a single scalar was used or scalars were developed for about each half of the time-series. Estimates of r for the DE treatments ranged between 0.33 and 1.08

and K estimates fell between 82,000 and 1.54• $10^8$ mt. NEFSC or NJ survey models featured r's of 0.83 and 1.12, respectively, while K was estimated as 54,000 and 57,000 mt. A biomass dynamic model using all three untransformed indices (necessitating an additional two scalars and two initial year survey parameters) estimated r as 1.80 and K as 42,000 mt (Table 9C).

Relative biomass (EB/K) estimates from these different trawl survey model formulations were in general agreement and indicated that biomass has been high and stable since 1996. Biomass estimates approached K in the most recent years. Relative biomass was generally lowest in the 1980s and increased rapidly during the early to mid-1990s. Timing and trajectories of this increase in biomass were more variable in the different models.

All trawl survey model formulations of relative F (F/r) indicated that F has been very low for the past decade. Relative F was high through 1989 and fell rapidly by 1993. The scale of the 1975-2003 scenario was generally over twice as high as all 1981-2003 scenarios, but the trajectory was similar over the years in common. Relative F was high (F at approximately r) and rising through1980 in this extended time-series; it then followed the previously described trajectory for the 1981-2003 models.

When up to five years of recent data were removed from the preferred model, parameters, F, and EB did not detectably change. Removal of up to seven years from the beginning of the time-series had a profound effect on estimates of K and s, and induced some variation in r and $U_0$. As up to seven years were sequentially removed from the beginning, K steadily dropped from about 41,000 mt to 22,000 mt; the scalar steadily rose. K and s were significantly correlated ($r = -0.85$, $P = 0.015$). Sequential removal of years from the beginning of the time-series generally caused estimated EB to fall and F to rise in the more recent years of the time-series, while preserving the general trend observed (low EB to high EB and high F to low F) when all years were retained.

Biomass dynamic models of trawl survey indices portrayed an Atlantic Coast weakfish stock that is now at very high biomass and subject to little F. These results seem contradictory to landings that have continuously declined since 1998 and are now the lowest in the time-series, unless the stock is now comprised of individuals too small to be of interest to recreational and commercial fisheries (a stunted population) or fishers have become disinterested in weakfish.
These results are supportive of results obtained in the previous assessment (1981-2000) with biomass dynamic models, ADAPT VPA and ICA VPA (Kahn 2002b; de Silva 2002; Uphoff 2002a, 2002b). All survey based biomass dynamic models in this analysis indicated that biomass was low in the 1980s and then experienced a rapid recovery in the early to mid-1990s; estimated F was excessive in the 1980s, dropped precipitously in the early 1990s, and stabilized at a minimally low level afterwards. Biomass may now be near carrying capacity. Significant reductions in F and biomass recovery would have occurred prior to what were considered significant management measures in Amendment 3 to the Weakfish FMP ( Lockhart et al. 1996).

Biomass dynamic models of trawl survey indices portrayed an Atlantic Coast weakfish stock that is now at very high biomass and subject to little F (Figure 29). These results are supportive of results obtained in the previous assessment (Kahn 2002b). All survey-based biomass dynamic models in this analysis indicated that biomass was low in the 1980s and then experienced a rapid recovery in the early to mid-1990s; estimated F was excessive in the 1980s, dropped

precipitously in the early 1990s, and stabilized at a low level afterwards. Results of these models indicate that biomass may now be near carrying capacity. According to model results, significant reductions in F and biomass recovery occurred prior to what were considered significant management measures. These results seem contradictory to landings that have continuously declined since 1998 and are now the lowest in the time-series, unless the stock is now comprised of individuals too small to be of interest to recreational and commercial fisheries (a stunted population) or fishers have become disinterested in weakfish.

## RELATIVE AND SCALED-UP ABSOLUTE F, STOCK BIOMASS, SURPLUS PRODUCTION AND SURPLUS PRODUCTION MODELS.

### Biomass-based Relative Abundance Indices

A time series (1982-2004) of weakfish relative biomass indices were derived as a ratio between annual recreational weakfish catches (MRFSS: A + B1 +B2) in weight and total fishing effort data from the private boat sector based on the MRFSS annual surveys:

$$RelWt = MidWt / Effortt , \qquad (1)$$

Where RelWt denotes a biomass-based relative abundance index, MidWt is the recreational catches in weight from the private/rental boat mode of the MRFSS for the Mid-Atlantic region (New York through Virginia) in year t and Effort is the annual total trips of the private/rental boat mode in the Mid-Atlantic region in year t.

The resulting age aggregated (ages 1+) indices (Table 10) were confined to the private boat recreational catch and effort data from the Mid Atlantic subregion (New York to Virginia). This approach seemed justified because private boat catches from this subregion have, in most years, comprised a large (> 60%) percentage of the coast-wide recreational catches. Also, the private boat catch and effort estimates from the Mid Atlantic subregion have been measured with relatively high precision (relative CV < 0.13). Moreover, the private boat fishery is highly mobile and, unlike most trawl surveys, capable of catching larger (> 60 cm.) weakfish throughout their range. Since the MRFSS has monitored weight (kg) data from only the harvest (A, B1), the catch in weight of released weakfish (B2) was derived indirectly by assuming that the average weight (kg) of released fish (B2) was the same as the average weight of harvested fish. Although released weakfish caught in the recreational fishery are likely to weigh less than harvested fish, particularly after the imposition of minimum size limits in 1994, there is no known time series (1982-2004) of weight measurements on released fish with which to verify our assumption. Also, if recreational harvest (A, B1) in weight was used instead of total catch in weight (A, B1, B2) in the numerator of equation (1), the resulting indices after 1993 would be underestimated. Beginning in 1994, minimum size limits and daily creel limits were imposed coast-wide on the weakfish recreational fishery, thereby reducing weakfish recreational harvest from 1994 to 2005. Note that our indirect approach of estimating the B2 catch in weight in this context has also been used to estimate the B2 discards in weight for the current ADAPT VPA.

The abundance indices via equation (1) were based on total private boat fishing effort from the Mid Atlantic subregion rather than from directed fishing effort on weakfish (Table 10). In a

previous analysis (Crecco 2005d), the time series (1982-2004) of directed fishing effort from the Mid Atlantic private boat fishery was used to estimate weakfish abundance indices. Since the direct and total fishing effort time series was highly correlated (Pearson $r = 0.96$, $P < 0.0001$), the trend in abundance indices derived from total and directed effort was nearly identical and therefore the use of directed fishing effort would not have altered this analysis.

While this index is fishery dependent, problems of autocorrelation between it and coast-wide landings should be relatively minor for three reasons. First, commercial landings and discards have comprised, in most years, at least 65% of the total weakfish harvest. Thus, the Mid Atlantic private boat indices from 1982-2004 utilizes only about 20-30% of the total annual harvest in the index including the commercial harvest, thereby minimizing autocorrelation to the coast-wide landings. Second, the indices were based on the Mid Atlantic private boat catches (A, B1 B2) that include released fish instead of the harvest (type A and B1). This should further minimize the degree of autocorrelation with the total coast-wide harvest. Finally, the weakfish indices were based on the ratio of private boat recreational catch to fishing effort. This extra step of dividing catch by effort should reduce the probability of autocorrelation since the time series of coastwide harvest was inversely related (Pearson $r = -0.51$, $P < 0.006$) with private boat fishing effort from the Mid Atlantic region.

**Fishing Mortality, Stock Biomass and Surplus Production**

Relative fishing mortality estimates were also derived from 1982 to 2004. Relative F was estimated as a ratio of annual landings (commercial and recreational plus discards in mt) of ages 1+ weakfish in year t to the average of relative abundance indices in years t and t+1:

$$RelFWt = HARVt / [(RelWt + RelWt+1)/2] , \qquad (2)$$

where RelFWt is the biomass-based relative F for year t, HARVt is the total harvest in metric tons including estimated weight of discards for year t, RelWt is the relative abundance index for year t and RelWt +1 is the index for year t+1 (Table 10). Since the index is not yet available for 2006, an estimate of relative F for 2005 cannot be derived via equation (2). Instead, an approximate estimate for 2005 was derived as a ratio of the preliminary 2005 landings to the 2005 index. Note that the 2005 weakfish recreational landings and discards (mt) are available from the MRFSS, but the 2005 commercial landings and discards are not yet available. A preliminary 2005 coast-wide harvest estimate (commercial and recreational plus discards) was derived by dividing the 2005 recreational coast-wide harvest and discards by the 0.45, which was the ratio of 2004 recreational harvest to the 2004 total harvest.

The next step in this analysis was to transform relative F estimates into units of absolute biomass-weighted fishing mortality of ages 1+ weakfish. This transformation was made by multiplying the relative F estimates values from 1982 to 2005 by a scalar consisting of the ratio of the average biomass weighted F (ages 1+) from run 20 of ADAPT VPA for 1987-1991 to the average the relative F estimate from 1987-1991 (Crecco 2005b). The VPA F estimates were confined here to the 1987 - 1991 period because the 1987-1991 F estimates from the VPA were fully converged and therefore robust to retrospective bias noted from more recent (1999-2003) F estimates (Table 10).

Average stock biomass (mt) of ages 1+ weakfish was estimated from 1982 to 2004 as a ratio of coastwide harvest to the scaled biomass weighted F:

$$Biot = HARVt / FWt,. \quad (3)$$

where Biot is the stock biomass for year t, HARVt is the harvest in year t in metric tons, including discards, and FWt is the biomass-weighted F for year t (Table 11).

A time series (1982-2004) of weakfish surplus production estimates from 1982-2004 was derived by subtracting weakfish stock biomass in year t from stock biomass in year t+1 followed by the addition of annual total landings (mt) in year t:

$$SURPt = Biot1 - Biot + HARVt , \quad (4)$$

where SURPt is surplus production in year t, Biot+1 is the stock biomass in year t + 1, Biot is stock biomass in year t and HARVt is harvest in year t (mt) including discards (Table 11). Surplus production estimates have been used to monitor trends in per capita stock productivity for exploited finfish populations (Jacobson et al 2002).

Biomass weighted fishing mortality estimates on weakfish rose steadily from about 0.41 in 1982 to peak levels in 1988 (FW1988 = 1.08) (Table 10). The F estimates remained relatively high (FWt range: 0.60 to 0.81) from 1989 to1992, then fell steadily to below the 0.40 level in most years from 1993 to 2005. The 2004 and 2005 FWt estimates were around 0.25.

Weakfish biomass levels remained relatively high between 15,000 and 34,000 mt from 1982 to 1988 then fell consistently below 10,000 mt from 1989 to 1993 (Table 11). Biomass rose abruptly to above 20,000 mt from 1994 to 1999, then weakfish biomass fell steadily thereafter to the lowest level in the time series in 2004 (5,700 mt). The preliminary 2005 biomass level of 7,300 mt is about 28% higher than the 2004 estimate, but the 2005 level is the third lowest in the time series (Table 11).

The time series of weakfish surplus production from 1982 to 2004 generally followed the trend in stock biomass (Table 11). Weakfish surplus production remained relatively high from 1982 to 1986 and again in 1993 and 1994, but levels fell greatly after 1997 and remained low thereafter despite relatively low and stable fishing mortality (Table 10). Weakfish surplus production estimates were negative in 2000 and 2002, indicating the absence of sustainable harvest in those years. Surplus production estimates were positive in 2003 and 2004, but were below the estimates prior to 1999 (Table 11).

**Biomass Weighted Natural Mortality (MWt)**

Most of the current evidence (Uphoff 2005b; Crecco 2005c) suggests that the recent decline in weakfish surplus production is likely due to a recent rise in weakfish natural mortality (M) linked to enhanced predation and perhaps inter-specific competition. It would be useful to estimate a time series of age aggregated (ages 1+) natural mortality (M) rates and relate the M time series

statistically (stepwise regression model) to the candidate finfishes and abiotic factors. Statistical support for the Predation Hypothesis would be evident if the time series of one or more of the candidate finfish predators were positively correlated ($P < 0.05$) to the trend in weakfish natural mortality. Standard output from the ADAPT VPA includes biomass weighted fishing mortality (Fvpa) rates of ages 1+ weakfish from 1982 to 2003. Recall that the natural mortality rate (Mvpa) in all VPA runs was assumed to be constant at 0.25 across all ages and years. As a result, biomass weighted total mortality (ZWt) rates from 1982 to 2003 were easily derived by adding 0.25 to each of the aggregated age 1+ F values from the VPA run #20 that included MRFSS recreational cpue as the sole tuning index. The Weakfish Stock Assessment Subcommittee chose run #20 as the preferred VPA model run. The degree of retrospective bias in recent F and weakfish stock size estimates from run #20 was much less extensive than the bias for other model runs that were tuned by either trawl survey indices alone, or a combination of trawl survey and MRFSS indices. Note that scaled biomass (ages 1+) weighted fishing mortality (FWt) have been estimated independently from the VPA via equation 2 (Table 10). As a result, a time series of biomass weighted natural mortality rates (MWt) of ages 1+ weakfish were calculated from 1982 to 2003 by subtracting the biomass weighted FWt estimates (Table 10, Figure 34) from total mortality estimate (ZWt) estimates based on the VPA run #20.

Although natural mortality of age 1+ weakfish was assumed to be constant in previous Yield-per-Recruit and VPA model runs, the trend in annual biomass weighted natural mortality (MWt) from 1982 to 2003 does not support this assumption (Figure 34). Annual (MWt) estimates for ages 1+ weakfish were highly variable with systematic trends occurring from 1982 to 2003 (Table 10). Weakfish MWt levels from 1982 to 1986 remained relatively high, ranging from 0.44 to 0.82. Weakfish MWt levels fluctuated greatly between 1987 and 1995 from a high of 0.64 in 1988 to a low of 0.01 in 1989 (Figure 34). After 1995, however, weakfish natural mortality (MWt) rose steadily from 0.31 in 1996 to a high of 1.09 in 2002. Not only was annual weakfish MWt levels not constant from 1982 to 2003, but the long-term (1982-2003) average MWt level derived here (mean MWt = 0.47, SE = 0.06) was significantly higher (t-statistic = 3.67, $P < 0.01$) than the assumed constant M = 0.25.

**Age 0 Mortality**

One major problem in quantifying predation or other trophic responses on weakfish is pinpointing the period in the life history where the highest predation risk takes place. A temporal shift in predation mortality can occur across many weakfish ages (ages 0+) or may be confined mainly to a single age group (i. e. age 0 mortality). Since age 0 weakfish rarely exceed 18 cm TL, this early stage is particularly susceptible to a heightened risk of mortality from a vast array of potential finfish predators. Several recent predation studies (Beck 1997; Wahle 2003) have shown that size dependent mortality during the juvenile stage may lead to a demographic bottleneck which can inhibit the flow of recruitment to older ages. If this bottleneck is severe and persists over time, prey abundance will eventually cascade downward, resulting in a stock collapse emanating from the youngest to the oldest ages (i. e. bottom-up effect). To examine whether or not a demographic bottleneck may occur for age 0 weakfish, a time series of relative weakfish juvenile mortality (Z0) estimates was derived for the 1982 to 2003 year-classes. The Z0 estimates were expressed by a log ratio between coast-wide age 1 abundance (N1t+1) in year t+1 to the mean coast-wide juvenile abundance index (N0t) in year t:

$$Z0 = - \log (N1t+1 / N0t) . \qquad (5)$$

Weakfish juvenile abundance (N0) has been monitored along the Atlantic coast from Rhode Island to North Carolina including the South Atlantic (SEAMAP) from 1982-2004. Nine juvenile surveys (Table 12) were used to construct an average coast-wide index (N0) from 1982 to 2004 (see Section for more details). The abundance indices were expressed as the geometric mean catch per tow or geometric mean catch per seine haul, resulting in indices of vastly different magnitude. As a result, before the indices from the nine surveys were combined into a coast-wide average index (N0), the relative abundance values for each survey had to be standardized to equivalent abundance units. Equivalent units were established in a three-step process. First, the long-term (1982-2004) geometric mean abundance index was derived annually for the recruitment time series of each of the nine surveys. Second, a scalar for each data set was derived as a ratio of the long-term average index to the long-term average New Jersey index. Each annual index from each data set was then multiplied times the respective scalar, thereby transforming the magnitude of the eight indices to units of the New Jersey indices (Table 13). Finally, the coast-wide geometric mean index (N0) was derived as the grand mean across the scaled indices from 1982-2004 (Table 13).

A brief description of each of the nine juvenile trawl surveys is given below. The Rhode Island Division of Fish and Wildlife has conducted a juvenile finfish trawl survey in Narragansett Bay from 1982 to 2004. Juvenile weakfish abundance was expressed annually by the geometric mean catch/tow. The Connecticut DEP trawl survey has employed a stratified random design based on 120 tows per year. Tows have been conducted biweekly with a 42 ft otter trawl throughout Long Island Sound from April to June and from September to October. The survey data on weakfish are available from 1984 to 2004. Juvenile and age 1 weakfish (geometric mean catch/tow) have been primarily sampled by this trawl survey. The New York Division of Fish, Wildlife and Marine Resources has conducted a juvenile trawl survey from 1985 to 2004 using a 16 ft. trawl targeting juvenile estuarine finfish in the Peconic Bay of Eastern Long Island. Juvenile weakfish abundance was expressed annually by the geometric mean catch/tow. New Jersey has conducted an ocean trawl program from 1989 to 2004 using a stratified random design. Relative abundance (geometric mean catch/tow) of juvenile and ages 1+ weakfish have been monitored annually from August and October based on 78 tows/year. The Delaware Division of Fish and Wildlife conducts a juvenile trawl survey in Delaware Bay with a 16 ft. trawl from 1982 to 2004. Juvenile weakfish abundance was expressed annually by the geometric mean catch/tow. The Maryland Department of Natural Resources has conducted a juvenile trawl survey in Chesapeake Bay from 1980 to 2004 using a 16 ft. otter trawl. A time series of juvenile weakfish abundance was expressed annually by the geometric mean catch/tow. The Virginia Institute of Marine Science (VIMS) has conducted a trawl survey in lower Chesapeake Bay from 1987 to 2004. A time series of juvenile weakfish abundance (geometric mean catch/tow) was derived annually using August-October tows from three river tributaries. The North Carolina Division of Marine Fisheries has conducted a juvenile trawl survey in Pamlico Sound from 1987 to 2004. A time series of juvenile weakfish abundance was expressed annually by the geometric mean catch/tow. The Southeast Area Monitoring and Assessment Program (SEAMAP) has conducted trawl surveys of juvenile and adult (ages 1+) weakfish since 1989 which sample from

Cape Hatteras to Cape Canaveral. A time series (1989-2004) of juvenile abundance has been expressed as the geometric mean catch/tow.

A time series (1982-2004) of weakfish age 1 abundance estimates (N1 in millions of fish) used in the numerator of equation (5) was taken directly from run #20 from the VPA (Table 13). The N1 estimates from run #20 were derived independently of the relative juvenile abundance estimates (Table 12) since none of the juvenile indices were used to tune run # 20. Note that the juvenile abundance indices in the denominator of equation (5) are expressed in relative units. Thus, the juvenile total mortality rates (Z0) are relative mortality estimates in contrast to the ages 1+ natural mortality estimates (MWt) from the previous section that are absolute mortality estimates based on total abundance data from run #20 of the VPA. Also, note that the current VPA generated age 1 abundance estimates (t+1) for the 1981 to 2002 year-classes during the years 1982 to 2003. Since there is currently no 2004 age 1 index that represents the 2003 year-class, age 1 abundance for the 2003 year-class was assumed to be the same as the age 1 abundance estimate for the 2002 year-class (Table 13). Given the steady decline in age 1 abundance (N1) from the VPA from 1997 to 2002, this assumption seemed reasonable. The age 1 abundance (N1) values from the VPA were occasionally larger than the magnitude of the coast-wide juvenile index (Table 13) resulting in some negative values of mortality (Z0) via equation (5). In order to generate mortality rates (Z0) as positive integers, all age 1 abundance data (N1) were scaled down by dividing the N1 values by an arbitrary value of 9.0.

Weakfish juvenile indices varied greatly across the nine surveys for the 1982 to 2004 year-classes (Table 12). In the Rhode Island survey, juvenile indices remained relatively high from 1982 to about 1999, then juvenile year-class strength after 1999 dropped quickly to low levels. Juvenile indices from other state survey, however, exhibited a general rise in year-class recruitment after 1995 (Table 12). When the nine juvenile data sets were standardized and combined into a mean coast-wide index (N0) (Table 13), the coast-wide weakfish juvenile recruitment showed a fairly persistent rise after 1994 (Figure 32). The persistent rise in juvenile recruitment after 1998 coincided with a pronounced drop in weakfish ages 1+ biomass (Table 11), indicating the presence of compensatory survival from the larval to juvenile stage. Abundance of age 1 weakfish (N1J) based on run #20 of the VPA varied without trend from 1982 to about 1995, then age 1 abundance fell steadily from 1996 to 2003 (Figure 33) in sharp contrast to the general rise in juvenile recruitment after 1995. The resulting weakfish juvenile mortality (Z0) estimates increased in magnitude for the 1995 to 2003 year-classes (Figure 33). These findings strongly suggest that recent natural mortality on juvenile weakfish increased systematically since 1995 consistent with the recent emergence of a trophic bottleneck that may have interfered with the flow of recruitment from age 0 to ages 1+.

## PREDATION HYPOTHESIS

Coastwide weakfish biomass (mt) has fallen steadily by 65% since 1999 to levels well below the estimated Bmsy threshold. Total mortality (Z) estimates from both the VPA (run #20) and cohort catch curves have risen sharply since 1996 but biomass weighted F estimates (ages 1+) during this period have remained low and steady (Crecco 2005a). Moreover, annual changes in average annual F (lagged or unlagged) from 1982 to 2004 exhibited no statistical relationship (Pearson $r = 0.22$, $P < 0.31$) to changes in weakfish surplus production (Crecco 2005b),

suggesting that the recent failure in weakfish productivity is not related to fishing effects. As a result, the sudden and unexpected drop in weakfish productivity since 1998 is thought to be due to a systematic rise in weakfish natural mortality (M). This increase in M is likely due to one or a combination of biotic and abiotic factors including a rise in finfish predation, enhanced interspecific competition for food and perhaps a major temporal shift in key environmental variables that could play a role in affecting weakfish recruitment.

Statistical and empirical evidence gathered thus far supports a Predation Hypothesis involving striped bass (*Morone saxatilus*) as a primary predatory finfish on weakfish (Uphoff 2005a, 2005b; Crecco 2005a, 2005c). Striped bass abundance along the Atlantic coast has recently risen to record high levels after 1998 (ASMFC 2005) coincident with the recent failure in weakfish productivity. Although statistical and empirical evidence linking striped bass to the recent failure in weakfish productivity is persuasive, there is yet no direct evidence that ties the recent increase in weakfish M directly to striped bass predation. Also, the weakfish age(s) at which the risk of predation is highest has yet to be established. Since predation is generally regarded as a major force structuring marine fish communities (Bax 1991), it would be useful in this context to present an analytical model that merges the population dynamics of weakfish with the foraging characteristics of striped bass. In addition, to provide a more thorough examination of the Predation Hypotheses, other candidate finfish predators on weakfish such as bluefish, summer flounder and spiny dogfish need to be considered as well as potential competitors of weakfish. Finally, systematic changes in finfish productivity may respond to high frequency climatic changes over broad geographical areas (Scheffer et al. 2001). Thus, a more complete examination of temporal shifts in climatic variables, such as water temperature and long-term deviations in the North Atlantic Oscillation Index, need to be considered as an alternative to the Predation hypothesis.

In this section, we used the age-aggregated Steele and Henderson (1984) (S-H) production model to further examine the joint effects of fishing and predation on Atlantic coast weakfish. The S-H model has extensive theoretical appeal since it incorporates the compensatory stock dynamics of the prey (weakfish) with fishing effects plus a sigmoid foraging response by the predatory finfish that may lead to critical depensation at low prey abundance (Spencer and Collie 1997). Since the S-H model can also accommodate climatic variables (Spencer 1997), this modeling approach represents a modest but straightforward attempt at ecosystem modeling. In this section, the S-H model was used to re-estimate overfishing thresholds (Fmsy, Bmsy) for weakfish in the presence of finfish predation. In addition, more robust and precise estimates of the overfishing thresholds (Fmsy, Bmsy) from the S-H model were attempted through iterative reweighted least squares regression. Model validation and an analysis of process error were also undertaken by an examination of residual patterns. As first indicated by Uphoff (2005c), the predation exponents estimated directly from S-H model can be used to derive weakfish natural mortality rates (Mp) associated with striped bass predation. In this section, a time series (1982-2004) of Mp values was compared to the magnitude and trend in age aggregated annual MWt estimates (ages 1+) derived independently from run # 20 of the VPA (i. e. M = Z-F) combined with biomass weighted fishing mortality rates. A direct causal link between the rise in weakfish natural mortality and striped bass predation would be established, if the 1982-2004 predator-related Mp estimates derived empirically from the S-H model closely track the weakfish ages 1+ M estimates. Finally a stepwise multiple linear regression model was used to identify additional

explanatory variables that may be linked to changes in weakfish surplus production, weakfish natural mortality (MWt) and weakfish juvenile total mortality from 1982 to 2004. These explanatory variables included other finfish predators (i.e. summer flounder, bluefish and spiny dogfish), a potential finfish competitor of weakfish (Atlantic croaker) and selected climatic variables (mean annual water temperatures (C) and annual deviations in the North Atlantic Oscillation index).

**Statistical Analysis**

A stepwise multiple regression model (SAS 2002) was used to identify several key biotic and abiotic factors that may be linked statistically ($P < 0.05$) to changes in weakfish surplus production (SURPt), weakfish natural mortality (MWt) and weakfish juvenile mortality (Z0) from 1982 to 2004. The stepwise analysis was conducted separately using surplus production (SURPt), age aggregated (ages 1+) natural mortality (MWt) and age 0 mortality (Z0) as dependent variables in the three stepwise models. Explanatory variables in the three model runs included biomass weighted fishing mortality (FWt), as well as stock abundance of several candidate finfish predators on weakfish such as striped bass, bluefish, summer flounder and spiny dogfish (Table 14). Striped bass is regarded as a voracious predator from the Mid and North Atlantic on menhaden, gizzard shad and herring (Hartman 1993). Larger (> 60 cm) striped bass, however, have been reported to undergo an ontogenic shift in prey preference from herring and small menhaden to spot and weakfish in Chesapeake Bay (Hartman and Brandt 1995; Walter and Austin 2003). Bluefish (*Pomatomous saltatrix*) also prey upon a variety of finfishes including weakfish throughout the Atlantic coast (Bowman et al. 2000). Larger (> 50 cm) summer flounder (*Paralichthys dentatus*) (Bowmann et al 2000) also prey on a variety of finfishes including smaller (< 20 cm) weakfish from mostly the North and Mid Atlantic. By contrast, spiny dogfish (*Squalus acanthias*) are found coast-wide and are regarded as a primary finfish predator of river herring, capelin, and sand lance (Bowmann et al 2000), although Rountree (1999) reported that spiny dogfish also prey upon smaller weakfish.

A time series of Atlantic croaker (*Micropoganias undulatus*) abundance was also included as a potential competitor of weakfish (Table 14). The ecological role of Atlantic croaker as a potential competitor or predator on weakfish is poorly understood but croaker trophic status is thought to be somewhat below that of weakfish (Miller et al 2004). Thus croaker may compete with or prey upon small weakfish particularly in Mid Atlantic waters during spring when both species overlap. Potential weakfish predators and competitors are thought to undermine weakfish surplus production by enhancing weakfish natural mortality or by constricting the flow of age 0 recruitment (i. e. trophic bottleneck). As a result, one or more the candidate finfishes in the model would be identified as a potential stressor on weakfish surplus production if the respective regression slope(s) associated with each finfish in the stepwise regression was negative and statistically significant ($P < 0.05$). Conversely, in the analyses with weakfish ages 1+ natural mortality (MWt) and juvenile mortality (Z0) as dependent variables, support for the Hypothesis would be given if the slope(s) for one or more of the candidate finfishes were positive and statistically significant ($P < 0.05$). Fishing mortality estimates (FWt) were also included as an explanatory variable to further test the overfishing hypothesis. If, for example, fishing mortality (FWt) was positively correlated ($P < 0.05$) to the recent rise in age aggregated (ages 1+) natural

mortality (MWt), this might imply that discard losses due to fishing have been severely underestimated in the catch-at-age matrix used in the VPA model.

In this analysis, annual abundance of four out of five candidate finfish (striped bass, summer flounder, bluefish, and spiny dogfish) was taken from the most current assessment of that species (Table 14). Coast-wide biomass (mt) of spiny dogfish was expressed annually as thousands of metric tons by the area swept approach based on the NEFSC spring trawl survey (Matt Gates, ASMFC spiny dogfish Technical Committee pers. comm.). Coast-wide striped bass, summer flounder (fluke), and bluefish stock abundance estimates from 1982 to 2004 were taken from the most recent ADAPT VPA runs (ASMFC web site, 2005). Fluke abundance from 1982 to 2004 was expressed as spawning stock biomass in mt based on the 2005 VPA. Bluefish abundance was expressed each year as millions of pounds of ages 1+ fish based on the ASAP model. In the case of the Atlantic croaker, stock size estimates from the VPA are only available from 1982 to 2002. For this reason, the 1982-2004 total recreational catch of croaker (A, B1, B2) from the MRFSS was used as a coast-wide index in the stepwise regression (Table 14). Croaker abundance each year was represented by the total catches (A, B1 and B2) from the Mid Atlantic subregion. Use of croaker recreational catches as a stock index seemed justified, given that the 1982-2002 recreational catches were highly correlated (Pearson $r = 0.80$, $P < 0.0001$) to the 1982-2002 VPA abundance estimates. Striped bass abundance was expressed as millions of ages 8+ fish from the 2005 VPA. The striped bass VPA tended to overestimate recent (2002-2004) F levels and therefore underestimate recent (2002-2004) stock sizes. As a result, a second time series of ages 7+ stripers (millions of fish) was also used in the stepwise model based on the ratio of ages 7+ landings to tagged-based F estimate of ages 7+ stripers (Kahn 2005b). Given that recent (2002-2004) tag-based F estimates were 20% to 40% lower than the corresponding F estimates from the VPA, the tag-based abundance estimates exhibited a more pronounced rise from 2002 to 2004 (Table 14).

Changes in large-scale climatic conditions could have also influenced the recent decline of weakfish surplus production by interrupting the formation of dominant year-classes. A time series of average annual surface water temperature (Temp, C) and deviations in the winter North Atlantic Oscillation (NAO) index (Table 14) were also included in the stepwise model as potential environmental forcing variables on weakfish surplus production. Since all female weakfish reach sexual maturity by age 2 (Wilk 1979), the Temp and NAO variables were lagged t-1 and t-2 years to coincide with weakfish recruitment to the adult stock. A time series (1980-2002) of average annual water temperatures was taken from a continuous temperature recorder located at the Millstone Nuclear Power Station, Waterford CT. Annual deviations in the NAO indices from 1980 to 2002 were taken from a recent American lobster manuscript (Fogarty and Gendron 2004).

The time series of weakfish surplus production (SURPt) from 1982 to 2004 (Table 11) was regressed in a stepwise model against the nine explanatory variables (Table 14). The stepwise model selected striped bass abundance based on the VPA (Strip) as the most significant ($P < 0.001$) explanatory variable that was inversely related to weakfish surplus production (Table 15). No other explanatory variable was selected at the $P < 0.05$ level in the stepwise model. The correlation matrix (Table 16) indicated that weakfish surplus production was also inversely related ($P < 0.05$) to striped bass abundance based on tagging (Strip2) and to Atlantic croaker

(Croak). The time series of tag-based striper abundance (Strip2) and croaker abundance (Croak) from 1982 to 2004 closely followed (co-linear) the trend in VPA-based striper abundance (Strip) (Table 14). Thus, due to the presence of substantial co-linearity, the stepwise model was unable to select either Strip2 or Croak as a second or third significant variable. None of the other six explanatory variables including fishing mortality (FWt) were negatively and significantly related ($P < 0.05$) to weakfish surplus production (Table 16). Statistical evidence given here strongly suggests that the recent failure in weakfish productivity was linked to predation and inter-specific competition with striped bass and perhaps Atlantic croaker.

The time series of biomass weighted natural mortality estimates (MWt) on ages 1+ weakfish from 1982 to 2004 (Table 10, Figure 34) were used as a response variable in a second stepwise model against the nine explanatory variables (Table 14). The stepwise model selected fluke (summer flounder) as the most significant ($P < 0.001$) explanatory variable (Pearson $r = 0.79$, $P < 0.0001$) that was closely tied to the trend in weakfish ages 1+ natural mortality (Table 15). No other explanatory variable was selected at the $P < 0.05$ level in the stepwise model. The correlation matrix (Table 16) revealed that weakfish natural mortality (MWt) was also positively related ($P < 0.05$) to both striped bass abundance estimates (Strip, Strip2). Since the time series of striped bass abundance from 1982 to 2004 closely tracked (co-linear) the trend in fluke abundance (Table 14), the stepwise model was unable to select either Strip or Strip2 as a second significant ($P < 0.05$) variable. None of the other six explanatory variables were positively and significantly related ($P < 0.05$) to weakfish ages 1+ natural mortality (Table 16). Statistical evidence given here strongly suggests that the recent rise in weakfish ages 1+ natural mortality (MWt) was linked to enhanced predation from fluke and striped bass.

The time series of juvenile weakfish mortality rates (Z0) from 1982 to 2004 (Table 13, Figure 33) were used as a response variable in a third stepwise model against the nine explanatory variables (Table 14). The stepwise model selected striped bass abundance from the VPA as the most significant ($P < 0.001$) explanatory variable that was closely tied (Pearson $r = 0.91$, $P < 0.0001$) to the rise in weakfish juvenile mortality (Z0) (Table 15, Figure 35). No other explanatory variable was selected at the $P < 0.05$ level in the stepwise model. However, striped bass abundance based on tagging (Strip) (Pearson $r = 0.81$, $P < 0.0001$) and Atlantic croaker abundance (Pearson $r = 0.85$, $P < 0.0001$) were both closely tied to the pronounced rise in weakfish juvenile mortality (Table 16). The correlation matrix (Table 16) also revealed that weakfish juvenile mortality (Z0) was, to a lesser extent, positively related ($P < 0.05$) to fluke (Pearson $r = 0.46$, $P < 0.03$). Since the time series of Atlantic croaker abundance from 1982 to 2004 closely tracked (co-linear) the trend in striped bass (Table 14), the stepwise model was unable to select croaker as a second significant ($P < 0.05$) variable. None of the other five explanatory variables were positively and significantly related ($P < 0.05$) to weakfish ages 1+ natural mortality (Table 16). Statistical evidence given here strongly suggests that the recent failure in weakfish productivity was due primarily to the emergence of a age 0 recruitment bottleneck linked to enhanced predation with striped bass and perhaps Atlantic croaker and fluke.

**Steele-Henderson (S-H) Model**

The age aggregated Steele-Henderson (S-H) production model (Steel and Henderson 1984) was used to re-estimate the overfishing thresholds (Fmsy, Bmsy) for weakfish with and without the

presence of a significant ($P < 0.05$) predator-prey response. The S-H model assumes the existence of compensatory density-dependent mortality for finfish populations, a position widely held by most fish population ecologists (Wahle 2003). All of the population dynamics processes (somatic growth, natural mortality and recruitment) in the S-H model are subsumed in the intrinsic rate of population increase (r) and to a lesser extent in the carrying capacity (K) parameters. Like all production models, successful fitting (precise and robust parameter estimates) from the S-H model requires a high degree of contrast in the time series (1982-2004) of weakfish biomass. Previous production modeling (Uphoff 2005a; Crecco 2005a) has thus far indicated that precise estimates (r, K) were obtained based on the 1982-2004 time series of weakfish landings and biomass estimates. The S-H model was originally expressed as a logistic production model with an added sigmoid function that reflected the foraging response by the predator. Previous weakfish production modeling indicated that the gompertz asymmetrical model was a better fit to the weakfish biomass data than the logistics model (Crecco 2005a, 2005b). As a result, the surplus production portion of the S-H model was converted from the logistics to the Gompertz form:

Biot+1= Biot+log(K)*r*Biot*(1-(log(Biot)/log(K)))- catcht-[(c*Predt*(Biot)**2)/(A**2+(Biot)**2)] (6)

where: Biot+1 = weakfish biomass (mt) in year t+1;
Biot = weakfish biomass (mt) in year t;
Predt = abundance of the predator in year t;
K = estimated carrying capacity of weakfish (mt);
r = intrinsic rate of population increase;
c = per capita consumption rate of the predator;
A = weakfish biomass (mt) where predator satiation takes place.

In the Gompertz model, Fmsy is expressed solely by the intrinsic rate estimate (r), whereas Bmsy is expressed as K/2.72, where 2.72 = exp 1 (Quinn and Deriso 1999). All parameter estimates (r, K, c and A) from the S-H model (equation 6) were derived from the NLIN procedure (Marquardt algorithm) contained in the Statistical Analysis System (SAS 2002). The S-H model was fitted to weakfish biomass (Biot, Biot+1) (Table 11) and one or more of the candidate finfish predators (Predt) (Table 14) by nonlinear least squares regression methods. Note that the choice of one or more of the candidate finfish predators (Predt) (Table 14) was conditional upon results from the stepwise regression analysis.

Given the potential for moderate to severe measurement errors in the input data, the S-H models was also fitted as a nonlinear robust regression using the iterative reweighted least squares method outlined by Holland and Welsch (1978). The algorithm and rationale for this approach is described in the current SAS (2002). This re-weighting scheme allowed the down weighting of data from certain years in the model where model residuals (regardless of direction) exceeded a previously defined threshold level. As indicated by Holland and Welsch (1978), the choice of a threshold is subjective and always represents a trade-off between minimizing the variances around the parameters (r, K, c and A) and at the same time generating globally converged parameter estimates. As suggested by Holland and Welsch (1978), a range of threshold estimates were used initially and the final threshold value was selected that satisfied the trade-off between global convergence of all parameter estimates and parameter estimates with maximum precision (minimum variance). The two step re-weighting approach always produced converged estimates (global estimates) that were within 10% of the parameter estimates (r, K, c and A)

derived by the ordinary least squares approach. However, the standard errors about the estimates based on iterative re-weighting were always 30 to 45% lower, resulting in much narrower confidence limits about the overfishing definitions (Fmsy, Bmsy) and the predation parameters (c, A).

As indicated by Steele and Henderson (1984), the S-H model (equation 6) is a conventional discrete time surplus production model:

Biot+1= Biot+log(K)*r*Biot*(1-(log(Biot)/log(K)))- catcht , (7)

that is merged with a type 3 predator functional response of the type:

[(c*Predt*(Biot)**2)/(A**2+(Biot)**2)] (8)

In previous weakfish surplus production modeling (Uphoff 2005a), the discrete logistics model in the absence of predation effects (equation 7) was shown to seriously over predict recent (1998-2003) weakfish biomass, leading to a clear trend in recent residuals. This clear residual pattern indicated that the conventional production model (equation 7) was highly uncertain especially for short-term predictions. Model uncertainty is usually caused by the failure to include one or more informative parameters, or by choosing the wrong form of the model. Note that a model with low levels of uncertainty will produce no systematic residual pattern over time. To further examine for potential model uncertainty, the discrete component (equation 7) of the S-H model (i. e. without predation effects) was fitted to the 1982-2004 weakfish biomass estimates (Biot, Biot+1) (Table 11). If a systematic pattern should emerge in the residuals based on the recent (1998-2004) observed and predicted weakfish biomass (Biot+1) estimates, then severe process errors would again be manifested in the model. Statistical support for the Predation Hypothesis would be evident, if the addition of the predator component (equation 8) to the S-H model (equation 6) not only improved the model fit, but also greatly reduced model uncertainty that had previously plagued the discrete production model (equation 7).

In an earlier weakfish report, Uphoff (2005c) noted that if the predation parameter estimates (c, A) from the S-H model are sufficiently precise, then a time series of weakfish biomass estimates (Dt) consumed annually by the predator (Predt) can be derived in the form:

Dt = [ (c*Predt*(Biot)**2) / (A**2 + (Biot)**2] . (9)

Once Dt estimates were obtained via equation (9), the instantaneous natural mortality rate (biomass weighted) ascribed to predation (Mp) can be derived:

Mp = Dt / [(Biot + Biot+1) /2]. (10)

Further empirical support for the Predation Hypthesis would be given if the biomass weighted natural mortality due to predation (Mp) on weakfish from 1982 to 2004 closely followed the trend in age 1+ weakfish natural mortality (MWt) estimates based on run #20 from the VPA.

The Gompertz surplus production model (equation 7) was fitted by nonlinear least squares regression to weakfish stock biomass in year t and t+1. This model did provide a good fit (r**2 = 0.68) to the biomass data with statistically significant (P < 0.05) r and K parameter estimates (Table 17). The resulting overfishing thresholds (Fmsy, Bmsy) for weakfish of 0.32 and 25,259 mt, respectively, were similar in magnitude to previous estimates (Table 17). However, this production model consistently over predicted weakfish biomass from 1998 to 2005 by 10 to 50% (Table 18), indicating that the Gompertz model was plagued by substantial model uncertainty. Although fitting the model (equation 7) by iterative reweighting least squares substantially improved the fit (r**2 = 0.82) and enhanced precision around the parameter estimates (r, K) and overfishing definitions (Fmsy, Bmsy) (Table 17), a severe residual pattern nevertheless persisted from 1998 to 2005 (Table 19). Severe model uncertainty, as indicated by a systematic trend in the residuals, usually indicates the absence of an informative parameter(s) to the model.

The full S-H production model (equation 6) was fitted by nonlinear least squares regression and iterative re-weighting to weakfish stock biomass in year t and t+1 (Biot, Biot1) and striped bass (Strip) as the potential predator (Tables 11 and 14). Both S-H model provided very good fits (r**2 = 0.88, 0.94) to the biomass and predation data with statistically significant (P < 0.05) r, K, c and A parameter estimates (Table 20). Overall, the S-H models was not only a better fit to weakfish biomass than the basic Gompertz model, but the r and K parameters, particularly from iterative re-weighting, were estimated with much higher precision. The resulting weakfish overfishing thresholds (Fmsy, Bmsy) from the nonlinear least squares S-H models for weakfish was 0.59 and 21,179 mt, respectively (Table 20). The overfishing thresholds (Fmsy,Bmsy) based on the iterative re-weighted S-H model was 0.55 and 23,400 mt, respectively (Table 11). The S-H model fitted by iterative re-weighting exhibited clear improvements in precision about the parameters (r, K, c and A) over the traditional least squares S-H model. Moreover, unlike the severe residual pattern evident from 1998 to 2004 based on the traditional gompertz models (Tables 18 and 19), there is little if any systematic residual pattern from the S-H model fitted by iterative re-weighting (Table 21). This indicated little if any uncertainty for the S-H model fitted by iterative re-weighting least squares. Finally, the time series (1982-2003) of predation-based natural mortality (Mp) from striped bass was derived via equations (9) and (10) (Table 22). The predatory mortality rates (Mp) rose in magnitude after 1997 coincident with a steady drop in weakfish biomass. This inverse relationship between Mp and weakfish biomass is consistent with the presence of depensatory density-dependent predation mortality which, if persistent over time, could be highly destabilizing to future weakfish population growth. Finally, the time series (1982-2004) of predatory natural mortality (Mp) was significantly correlated (Pearson r = 0.61, P <0.003) to the age 1+ natural mortality (MWt) values estimated independently (Table 22, Figure 36). These findings strongly suggest that the recent rise in weakfish ages 1+ natural mortality (MWt) coupled with the failure in weakfish productivity (SURPt) are tied directly to the increase in striped bass predation mortality (Mp).

Most of the statistical evidence given herein supports the Predation Hypothesis as the most reasonable explanation for the recent failure in weakfish productivity. Although results from the stepwise model identified striped bass, Atlantic croaker and fluke as primary weakfish predators (Table 15), striped bass was selected first over the other two in two (SURPT, Z0) out of three model runs. In the case of the stepwise model with ages 1+ natural mortality (MWt) as the response variable, striped bass was chosen second only to fluke as a major predator of adult

weakfish (Tables 15 and 16). Annual changes in fluke abundance from 1982 to 2004 were closely coupled to annual changes in weakfish ages 1+ MWt (Tables 10 and 14). Nevertheless, it is doubtful that this statistical relationship suggests a plausible causal mechanism. The mouth gape of even large (> 75 cm) fluke is relatively small (Olla et al. 1972) as compared to the mouth gape of other inshore apex predators such as striped bass and bluefish. The relatively small mouth size of fluke is primarily adapted to the consumption of invertebrates and small (< 25 cm) finfish prey. Therefore, larger fluke could conceivably prey heavily on age 1 weakfish (length range: 18-25 cm). However, it would be highly unlikely that even the largest fluke could prey effectively enough on ages 2+ weakfish to have caused the close positive fit (Pearson $r = 0.79$, $P < 0.0001$) given here between weakfish ages 1+ natural mortality and fluke abundance (Table 16). Therefore, we regard the promising statistical relationship given here between weakfish ages 1+ MWt and fluke abundance as a statistical artifact.

The close statistical coupling between the recent rise in weakfish juvenile mortality (Z0) and the parallel rise in striped bass and croaker abundance from 1982 to 2004 (Figure 35) implies that the recent emergence of a recruitment bottleneck at age 0 was due to predation. If this bottleneck persists over time, the flow of weakfish age 0 recruitment to older ages may become severely constricted, causing the weakfish stock to cascade downward from the bottom up. The contribution of croaker as a competitor or predator responsible for the weakfish recruitment bottleneck is difficult to establish at this time. Dietary studies of croaker are few in number (Miller et al 2004), but current research indicates that croaker, due to their relatively small size, eat mostly invertebrates (Overstreet and Heard 1978). The diet of croaker does overlap that of smaller (< 40 cm) weakfish, and like weakfish, larger (> 33 cm) croaker apparently undergo an ontogenic shift in diet from invertebrates to mainly fish (Miller et al 2004). Nevertheless, there is currently no empirical evidence that large croaker prey on weakfish of any size. On the other hand, since the diet of juvenile weakfish and croaker overlap, the strong statistical relationship given here between weakfish age 0 mortality and croaker abundance might indicate a rise in inter-specific competition for food between croaker and weakfish. If the outcome of recent inter-specific competition has favored croaker as indicated by the recent rise in croaker abundance (Table 14), somatic growth rates of age 0+ weakfish may have recently fallen, rendering juvenile and ages 1+ weakfish more susceptible to predation. This potential interaction between weakfish growth and predation mortality is directly supported by growth studies by Uphoff (2005b), who reported a steady decline in the coast-wide percentage of 13 in. + weakfish from 45.0% during the mid -1980's to about 1.0% in 2003. Although the strong statistical relationship between weakfish age 0 mortality and croaker abundance cannot be ruled out at this time, there is no empirical evidence thus far that Atlantic croaker are a major predator of juvenile weakfish.

The preponderance of statistical evidence given here supports the Predation Hypothesis involving striped bass as the primary predator of weakfish. Statistical evidence in support of the Predation Hypothesis consists of a strong inverse correlation (Pearson $r = -0.66$, $P < 0.0004$) between weakfish surplus production and striped bass abundance from 1982 to 2004 (Table 16). The strong correlation (Pearson $r = 0.91$, $P < 0.0001$) between weakfish juvenile mortality (Z0) and striped bass abundance (Figure 35) also suggests that the emergence of a weakfish recruitment bottleneck at age 0 was largely due to striped bass. Finally, striped bass mortality rates (Mp) on ages 1+ weakfish derived empirically from the S-H model from 1982 to 2003 were

closely correlated (Pearson r = 0.61, P < 0.002) to ages 1+ natural mortality (MWt) rates derived independently from run #20 of the VPA.

Although results from regression and production models alone do not demonstrate causality, recent empirical evidence is consistent with the Predation Hypothesis involving striped bass. Striped bass are known to consume finfish prey up to 60% of their own body length (Manooch 1973). Unlike large fluke and Atlantic croaker that prey mainly on small (< 22 cm) fish, large (> 76 cm) striped bass can easily prey on larger (> 40 cm) weakfish. In addition, the recent drop in weakfish productivity after 1997 was shown to have a spatial component that matched the distribution of striped bass. Weakfish landings and surplus production fell rapidly after 1998 from the Mid and North Atlantic subregions, but surplus production from the South Atlantic subregion had remained steady (Crecco 2005c). It so happens that anadromous striped bass are very abundant along the Mid and North Atlantic coast throughout the year, but are seldom encountered in any numbers south of Cape Lookout, NC. The predator assemblage south of Cape Lookout, NC is largely composed of Gulf Stream predators such as king mackerel and cobia etc. This well -defined spatial match between prey (weakfish) and predator (striped bass) clearly supports the validity of the Predation Hypothesis. Further empirical support of the hypothesis includes recent food habit studies of striped bass (Walter and Austin 2003; Ruderghausen et al 2005), indicating that weakfish and other sciaenids (spot) were primary food items of larger (> 60 cm) striped bass in Chesapeake Bay and Albemarle Sound. Moreover, a recent rise in striped bass abundance has been linked empirically to the steady decline of blueback herring in the Connecticut River and Albemarle Sound (Savoy and Crecco 2004; Rudershausen et al 2005), as well as with the menhaden decline from Chesapeake Bay (Uphoff 2003; Walter and Austin 2003). These findings suggest that the recent rise in striped bass production to record levels from 1997 to 2004 is largely responsible for the recent decline in weakfish productivity and sustainable yield.

The strong inverse relationship between striped bass mortality (Mp) rates (Figure 36, Table 22) and weakfish biomass since 1997 (Figure 37, Table 11) is consistent with the presence of depensatory density-dependent mortality. This phenomenon plus the apparent emergence of a weakfish recruitment bottleneck between ages 0 and 1 (Figures 32 and 33) makes stock rebuilding via the implementation of fisheries management measures an exceedingly difficult task. As indicated by Spencer and Collie 1997), fish stocks that are subject to moderate to severe depensatory predatory mortality, often undergo a sudden and persistent drop in surplus production over time even when fishing mortality rates have remained low for several years. Note that the biomass weighted fishing mortality (FWt) on ages 1+ weakfish have been below the Steele-Henderson Fmsy of 0.55 (Table 20) since about 1993 (Figure 36). Under depensatory predation, the weakfish stock is also expected to remain low and unresponsive to favorable climatic events and to further fishery management restrictions. Note that weakfish stock biomass has fallen steadily since 1999 to a 2005 stock biomass level of 7400 mt which is about 60% below the new Bmsy level of 23,400 mt (Table 20, Figure 37). The phenomenon of depensatory mortality, if driven largely by striped bass predation, could lead to a persistent and perhaps irreversible failure in weakfish productivity unless striped bass productivity in the next few years reverts back to pre 1998 levels.

The pessimistic outlook regarding the future of the Atlantic coast weakfish due to depensatory predation may be tempered somewhat by our findings of compensatory density-dependent survival during or before the juvenile stage. Compensatory mortality was manifested here by the recent and persistent rise in the coast-wide juvenile recruitment (N0) after 1995 (Figures 32) despite the pronounced drop in weakfish biomass after 1998 (Figure 37, Table 11). It is notoriously difficult to sort out the ramifications on future weakfish stock growth when both depensatory and compensatory mechanisms are operating simultaneously. However, the added stock resiliency due to compensatory processes at the juvenile stage may persist over several more years. If so, it may in fact overcome or at least balance out the adverse effects of depensatory predation, allowing the weakfish stock to achieve equilibrium at the current low levels for the foreseeable future.

The most restrictive management measures, such as a coast-wide moratorium to weakfish harvest, would reduce the 2004 F of 0.25 and landings to zero. A coast-wide moratorium would also reduce the high total mortality (Z) levels on ages 1+ weakfish by about 30% based on the 2004 ratio of fishing (F) to total mortality (F / Z). In a sense, the F/Z ratio is a relative measure of leverage that fishery managers can exert in order to enhance the chances of rebuilding depleted stocks. From 1982 to 1995, the F/Z ratios for weakfish were, in most years, well above 0.75, indicating the presence of relatively high leverage and thus a high probability that management measures if implemented then would have lead to stock rebuilding. As natural mortality (M) on ages 1+ weakfish increased after 1999 (Table 22), however, the F/Z ratios fell quickly below 0.35, thereby greatly reducing the likelihood that management measures imposed after 2005 would eventually lead to a weakfish stock recovery. This relationship between the probability of stock rebuilding via management action and the F/Z ratio was recently addressed by (Uphoff 2005d) by forecasting weakfish stock abundance over the next 20 years from the logistic production model. If M was allowed to remain at the 2003 level, he reported little if any future weakfish stock rebuilding following a 50% reduction in fishing mortality (F) if the current weakfish fishing mortality rates (F) on weakfish comprised less than 40% of total mortality (Z). The problem of weakfish stock rebuilding is made even worse by the emergence of a recruitment bottleneck at age 0 (Figure 33). Even a coast-wide moratorium to weakfish harvest would have little if any impact on the recently emergent recruitment bottleneck, where age 0 weakfish are not susceptible to direct harvest.

Like virtually all finfish stock assessments conducted along the Atlantic coast, natural mortality (M) of age 1+ weakfish was assumed to be constant (M = 0.25) in previous Yield-per-Recruit and VPA model runs. We found that the trend in annual biomass weighted natural mortality (MWt) from 1982 to 2003 did not support the constant M assumption (Table 10, Figure 34). Annual (MWt) estimates for ages 1+ weakfish rose steadily from 0.31 in 1996 to a high of 1.09 in 2002 (Figure 34). The management consequences of assuming a constant M when M actually rises systematically over time can be serious (Mertz and Myers 1997). As noted in this weakfish assessment, by holding M constant, the resulting ages 1+ fishing mortality rates (F) on weakfish would have risen steadily to around 0.85 in 2003 based on the VPA run #20. If the constant M assumption and ensuing VPA results were accepted without qualification, we would have concluded falsely that the recent failure in weakfish productivity was due to overfishing. In future assessments here and elsewhere, the assumption of constant M for ages 1+ fish needs to be critically examined. In addition, the impacts of trophic and environmental effects on exploited

finfish stocks should be integrated into fisheries models and rigorously tested as a potential alternative hypothesis to the overfishing hypothesis.

## STOCK PROJECTIONS

The weakfish assessment has evolved into aggregated biomass modeling after the failure of ADAPT VPA to provide accurate estimates of recent stock parameters (Crecco 2005a; Kahn et al. 2005). Crecco (2005) used external surplus production modeling (Jacobson et al. 2002) to estimate overfishing thresholds for weakfish. Surplus production models can be used as a basis for projections (Prager 1994), but the underlying assumptions of ecological stability (Spencer and Collie 1997) and dependence of changes in biomass on F in the model would render their utility doubtful in a situation where M is changing and likely the dominant factor driving biomass dynamics.

The current weakfish assessment provides the pieces for an external production modeling approach that does not require an assumption of ecological stability. Estimates of full time-series (1981-2003) of F and biomass (B) were provided in Crecco (2005) and Z was estimated with minimal or no retrospective bias through 2000 (Kahn et al. 2005). Therefore, biomass-based estimates of Z (F + M) were available through 2000. If Z is considered the negative counterpart of the intrinsic rate parameter (r′; Jordan and Coakley 2004), the Schaefer biomass dynamic model can be parameterized as

$$1)\ B_t = B_{t-1} + (r'-Z) \bullet B_{t-1} \bullet (1-(B_{t-1} / K)).$$

This estimate of r′ may not be equivalent to the standard estimate of r derived by production modeling because M can vary within the estimate of Z. In the discrete time-step form, an initial estimate of biomass, ($B_{1981}$), r′ and K are estimated. The latter two parameters are critical for projecting biomass under assumed levels and trajectories of annual F and M. This model was used to project biomass into the future under assumed levels of $F_t$ and $M_t$.

### Methods

Development of projections was a two-step process. First, r′, K, and $B_{1981}$ were estimated using the 1981-2000 estimates of $B_t$ from Crecco (2005) and Z from Kahn et al. (2005; VPA with MRFSS tuning only). Estimates of $B_t$ and $Z_t$ were ultimately based on MRFSS private boat catch per effort as a biomass index and catch estimates that included discards (Crecco 2005a; Kahn et al. 2005). Equation 1 was fit in an Excel spreadsheet using Solver to minimize $\sum$ (ln observed $B_t$ – ln predicted $B_t$). This was considered the base model for projections. Instantaneous annual fishing mortality rate in year t was estimated from predicted biomass as

$$(2)\ F_t = H_{t-1} / [(B_t + B_{t-1}) / 2] \text{ (Ricker 1975);}$$

where B is estimated from the equation 1 and H is harvest (including estimated discards).

The second step completed the estimates of $Z_t$ through 2003. Crecco's (2005) estimates of $B_t$ for 2001-2003 were assumed to be accurate. Goalseek in Excel was used to estimate $Z_t$ necessary to produce $B_t$ given the parameters estimated by equation 1. With estimates of $Z_t$ complete, $M_t$ could be estimated as $Z_t – F_t$ through 2002. Since $F_t$ in equation 2 was harvest based, $F_{2003}$ could not be estimated without projecting biomass forward and $F_{2002}$ represented the

last estimate in the time-series. An estimate of $F_{2003}$ was available from Crecco (2005), so M could be estimated for 2003 in this case.

Bootstrapping (N = 250) indicated precision of r′, K, $B_{1981}$, $B_t$, and $F_t$ of the base model for 1981-2003 data. To investigate model sensitivity, estimates of r and K from previous production models were used as a starting point (r = 1.17 and K =49,500 mt; r = 0.58 and K = 57,700 mt; and r = 0.90 and K =64,028 mt; predator-prey, Schaefer, and Gompertz, respectively; Uphoff 2005a; Crecco 2005a), held K constant, and estimated only r′ and $B_{1981}$.

Projections of biomass through 2025 used base model r′, K, $B_{2003}$ and mean estimates of $F_t$ and $M_t$ for 2001-2002 as a starting point. It was assumed that cuts in F would not occur until 2006, so biomass trajectory during 2004-2005 was based on a continuation of average conditions. Cuts were instituted in 2006 and maintained until 2025. Biomass trajectory was estimated for Z minus F • 0 (no action), F • 0.25, F • 0.5, F • 0.75, F • 1.0 (complete moratorium with no discard loss), F • 1.5, and F • 2.0. The latter two cuts implied instant reductions in M as well as F.

The Technical Committee (TC) requested simulations that depicted a gradual decline in M to a baseline of M = 0.25. This level of M equaled the constant estimate of M used in previous SARC reviewed weakfish stock assessments (NEFSC 1998; 2000) and in the ADAPT VPA in the current assessment (Kahn et al. 2005). Use of a baseline M other than 0.25 in projections may have required rerunning VPA and rescaled relative F analyses (V. Crecco, CT DEP, personal communication).

The model was modified to portray declines in M over time to a base level of M = 0.25. Scenarios were run of cuts in F (0, 25%, 50%, 75%, and 100%) with constant declines in $M_t$ to this baseline level. A decrease in M after 2006 until $M_t = 0.25$ was simulated as

$$(3)\ M_{t+1} = M_t \bullet ß.$$

Once $M_t \bullet ß = 0.25$ was reached, $M_t$ was held constant at 0.25.

To gain insight on how rapidly M could decrease, the trajectory of the increase in M during 1996-2001 (M increased from 0.29 to 1.13) was reversed to mimic a rate of maximum decline (ß). The estimate of M in 2002, 0.77, was not included because it was lower than the maximum estimated M in 2001 (1.13). Solver in Excel was used to estimate the initial M and ß in equation 1 that minimized the sum of squared differences between the observed and estimated M. The model was further constrained so that M in the final year was 0.25. This model predicted the change in M well ($r^2 = 0.99$) and estimated ß as 0.76. This estimate of ß was rounded to 0.8. Values of ß less than 0.8 tended to produce very similar results in previous projection exercises to ß = 0.8 (Uphoff 2005a; 2005b).

## Results and Discussion

The external production model fit the 1981-2000 biomass estimates well ($r^2 = 0.84$, $P < 0.001$; Figure 39). There was some serial patterning of residuals, with three to four year periods of over- or underestimation (Figure 39). Model parameters were estimated as r′ = 0.90, K = 86,409 mt, and $B_{1981}$ = 40,692 mt. Bootstrapping indicated these estimates were extremely precise, with a maximum difference of no more than 0.02% among these parameters. This precision carried

over to estimates of biomass and other parameters derived from biomass ($F_t$ and $M_t$). Base model estimates of $Z_t$ were 1.49 during 2001, 1.22 during 2002, and 1.45 during 2003.

Estimated $F_t$ was high during 1981-1991, typically 0.6 or greater (Figure 40). Fishing mortality fell to about 0.2 by 1999 and then began a steady rise to 0.4 by 2002. Estimates of $M_t$ were higher than $F_t$ during 1982-1984 and then plunged to near zero by 1987. $M_t$ varied from 0.2-0.5 during 1988-1998 and then increased to 0.8-1.1 during 2000-2002 (Figure 40).

Estimates or r′ were insensitive to values of K used in the external production models (Table 23). Even though estimates of K varied between 49,500 and 86,400 mt, estimates of r′ fell between 0.893 and 0.903 (Table 23). Estimates of r′ increased linearly as K increased. High precision in estimating r′ was important because the early phases of recovery would be dependent on it. Estimates of $B_{1981}$ varied somewhat among the model conditions and all were less than estimated in Crecco (2005; Figure 41). Biomass estimated by external production models with varying assumptions about K converged with each other by 1985 and were very similar through 2000. These estimates diverged somewhat from those in Crecco (2005; Figure 41). This pattern of agreement was exhibited with estimates of $F_t$ (Figure 42) and $M_t$ (Figure 43) as well. The increase in M since the late 1980s exhibited here corresponded with trends in $M_t$ from the Schaefer biomass dynamic model with a striped bass predation term (Uphoff 2005a).

Projections of biomass started in 2003 at 6,843 mt, $F_{current} = 0.41$, and $M_{current} = 0.95$. Modeled stock biomass dropped to about 2,000 mt before management actions were implemented in 2006 (Figure 44); this represented about 7% of mean 1998-2000 biomass that served as a target for recovery. Recovery was indicated once the mean 1998-2000 biomass (29,875 mt) was reached. The TC chose this value because it had been attained in the recent past; harvests and other attributes such as size quality were considered to be nearly recovered at that time. A value equal to 30% of K was considered as a target as well as a proxy for Amendment 4's 30% maximum spawning potential (30% MSP). This target was rejected because of substantial uncertainty of estimates of K among methods tried (Table 23) and the potential for it to change unexpectedly and drastically under the regime shift concept (Spencer and Collie 1995). Estimation of 30% MSP required equilibrium assumptions (constant growth and M) that could no longer be supported.

Weakfish biomass fell continuously in all cases when only $F_{current}$ was cut and $M_{current}$ was unchanged (Figure 44). In the two scenarios where current F was maintained or cut by 25%, weakfish became "extinct" (exploitable biomass = 0) after 2020 and 2025, respectively. Only the scenario of a completely effective moratorium, where discard mortality did not occur, kept biomass from falling to less than 100 mt by 2025. Under a completely effective moratorium, biomass was projected to fall to 875 mt in 2025 (Figure 44). Stemming the decline in weakfish biomass by managing the fishery alone seems unlikely based on these simulations unless the amount of Z attributed to F has been seriously underestimated (for instance, F is 0.8 instead of 0.4).

Biomass increased only when some depreciation of $M_{current}$ was part of the reduction in $Z_{current}$ (Figure 45; Table 23). Biomass slowly increased when $Z_{current}$ was reduced by $1.5 \bullet F_{current}$

starting in 2006. Recovery did not occur until 2025 with the 1.5 • $F_{current}$ cut (Figure 45). A cut in $Z_{current}$ equal to 2.0 • $F_{current}$ resulted in recovery by 2015 (Figure 45).

Without cuts in $F_{current}$, a decline to a baseline M of 0.25 when ß = 0.8 did not allow biomass to approach the level of recovery through the modeled horizon (2006-2025; Figure 46). If $F_{current}$ was cut by 25%, biomass recovered by 2024. When a 50% cut in $F_{current}$ was instituted, recovery occurred by 2021 and recovery to target biomass occurred in 2018 when $F_{current}$ was cut by 75% (Figure 46).

In light of the recent declines in landings, questions have been raised regarding the effectiveness of Amendment 3 of the FMP, imposed in 1995. The Amendment, bolstered by the federal Atlantic Coast Cooperative Fisheries Management Act, which made ASMFC management plans mandatory along the coast, included creel limits, minimum sizes, minimum commercial mesh sizes and restrictions on commercial effort. Following this, landings and relative abundance began to increase. A striking divergence appeared between the MRFSS estimates of total catch including discards (B2 component) and the estimated recreational harvest (A + B1 component) (Figure 2A). The former began rising well above estimates of the latter. This was the apparent conservation effect of minimum size limits and creel limits on the fishery. Previously, the two estimates had been almost identical. Estimates of scaled-up relative F have been relatively low and stable since 1995. ADAPT estimates of SSB showed increases in 1996 and 1997 before beginning the recent decline in 1998, according to Run 20. Abundance of the plus group began to increase after 1995 through 1999. Although this improvement in stock status did not persist, the technical committee strongly supports a continuation of at least the current fisheries conservation measures, because they had an apparent positive effect during the middle 1990s.

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## TABLES

Table 1A. Decision Table for Weakfish Management. Table entries are possible or probable results of the given management action, given a correct biological hypothesis.

| | **MANAGEMENT ACTION** | | |
|---|---|---|---|
| **BIOLOGICAL HYPOTHESIS** | **Restrict** | **Status Quo** | **Liberalize** |
| Stock Increasing | Probably lower yield; possible further stock growth | higher yield | much higher yield |
| Stock Stable | Reduced yield; stock growth | stable yield | higher yield at first, but stock could decline |
| Stock Declining | Even lower yield ; reduction in total mortality and possible reduction in stock decline; including possible stabilization or even increase | low and declining yield, continued stock decline(?) | Possible temporary increase in yield, then greater stock decline (?) |

**TABLE 1B. Evidence in support of the three hypotheses of stock status and trends in Table 1A.**

**1. Analyses and data supporting increasing stock hypothesis:**

- NMFS and NJ survey Total CPT
- results from ADAPT with trawl surveys as tuning indices (severe retrospective bias invalidates these results, though)
- ADAPT tuned to trawl surveys plus recreational catch per unit effort indices (again severe retrospective bias largely invalidate this)

**2. Analyses and data supporting stable stock hypothesis:**

- Biomass dynamics model with trawl survey tuning indices: stable and high

**3. Analyses and data supporting declining stock hypothesis:**

- decline in New Jersey age-structured trawl survey exploitable biomass catch per tow
- decline in Delaware age-structured trawl survey exploitable biomass catch per tow
- age structure truncation in Delaware trawl survey catch
- decline in recreational catch
- decline in commercial catch
- decline in recreational harvest per trip
- decline in recreational total catch per trip
- biomass dynamic models tuned to recreational fishery cpue indices
- results of ADAPT tuned to only recreational catch per unit effort as indices (again severe retrospective bias invalidates this result, however)
- decline in untuned cohort analysis through 1999
- length frequency analysis of Delaware and New Jersey survey catches (proportional stock densities) shows a decline in size structure
- stock size estimated by N = catch/F from scaled up F estimates.
-decline in surplus production through 2002

Table 2. Atlantic coast harvest of weakfish from 1981 through 2003, by sector and total.

| | RECREATIONAL HARVEST | | | COMMERCIAL LANDINGS | | TOTAL LANDINGS | |
|---|---|---|---|---|---|---|---|
| TOTAL YEAR | TOTAL CATCH, INCLUDING DISCARDS (A+B1+B2) | HARVEST IN NUMBERS (A + B1) | HARVEST IN POUNDS | POUNDS | COMMERCIAL PROPORTION OF HARVEST IN POUNDS | POUNDS | METRIC TONS |
| 1981 | 9,629,309 | 9,344,461 | 16,105,028 | 26,363,607 | 0.62 | 42,468,635 | 19,260.15 |
| 1982 | 2,044,670 | 1,854,090 | 8,285,326 | 19,478,274 | 0.70 | 27,763,600 | 12,591.2 |
| 1983 | 5,916,269 | 5,642,950 | 11,730,619 | 17,475,003 | 0.60 | 29,205,622 | 13,245.18 |
| 1984 | 3,769,040 | 3,520,811 | 7,013,781 | 19,773,587 | 0.74 | 26,787,368 | 12,148.47 |
| 1985 | 2,775,824 | 2,419,670 | 5,489,026 | 16,953,357 | 0.76 | 22,442,383 | 10,177.95 |
| 1986 | 10,973,586 | 8,664,122 | 10,141,786 | 21,187,973 | 0.68 | 31,329,759 | 14,208.51 |
| 1987 | 5,719,807 | 4,871,532 | 6,749,890 | 17,072,159 | 0.72 | 23,822,049 | 10,803.65 |
| 1988 | 6,446,383 | 5,626,268 | 6,331,649 | 20,526,402 | 0.76 | 26,858,051 | 12,180.52 |
| 1989 | 1,674,568 | 1,495,391 | 2,177,237 | 14,163,008 | 0.87 | 16,340,245 | 7,410.54 |
| 1990 | 1,671,808 | 1,232,253 | 1,347,260 | 9,438,260 | 0.88 | 10,785,520 | 4,891.39 |
| 1991 | 2,601,480 | 1,812,691 | 2,130,563 | 8,692,760 | 0.80 | 10,823,323 | 4,908.54 |
| 1992 | 1,667,809 | 960,151 | 1,398,980 | 7,453,788 | 0.84 | 8,852,768 | 4,014.86 |
| 1993 | 2,218,559 | 1,079,275 | 1,102,340 | 6,853,579 | 0.86 | 7,955,919 | 3,608.13 |
| 1994 | 4,928,951 | 1,826,495 | 1,795,517 | 6,190,520 | 0.78 | 7,986,037 | 3,621.79 |
| 1995 | 5,696,423 | 1,588,079 | 1,855,548 | 7,098,831 | 0.79 | 8,954,379 | 4,060.94 |
| 1996 | 7,306,298 | 2,269,330 | 2,925,392 | 6,940,578 | 0.70 | 9,865,970 | 4,474.36 |
| 1997 | 6,832,363 | 2,815,654 | 3,692,716 | 7,297,859 | 0.66 | 10,990,575 | 4,984.39 |
| 1998 | 5,697,395 | 2,386,345 | 4,044,974 | 8,424,725 | 0.68 | 12,469,699 | 5,655.19 |
| 1999 | 4,477,989 | 1651554 | 3,143,427 | 6,903,940 | 0.69 | 10,047,367 | 4,556.63 |
| 2000 | 6,727,052 | 2,089,202 | 4,154,794 | 5,372,672 | 0.56 | 9,527,466 | 4,320.85 |
| 2001 | 5,233,868 | 1526583 | 2,722,630 | 4,988,718 | 0.65 | 7,711,348 | 3,497.21 |
| 2002 | 3,289,765 | 1,171,889 | 2,192,607 | 4,767,232 | 0.68 | 6,959,839 | 3,156.39 |
| 203 | 2,098,056 | 497,571 | 864,962 | 1,970,291 | 0.69 | 2,835,253 | 1,285.83 |
| 2004 | 2,602,057 | | | 1,178,582 | | | |
| 2005 | | | | | | | |

Table 2A. Age and length sample intensity by half-year and state used for the catch-at-age calculations since the 30th SAW.NMFS (2000), which reviewed the weakfish assessment from 1982-1998. Age samples for the SEAMAP fall and NEFSC fall inshore surveys were produced by Dr. Charles Wenner, South Carolina Department of Natural Resources.

| YEAR | SEASON | STATE | AGED | MEASURED FROM COMM LANDINGS | COMM LANDINGS MT | COMM LENGTHS / MT | MEASURED FROM REC LANDINGS, MRFSS | RECREATIONAL LANDINGS, MT | REC LENGTHS / MT |
|---|---|---|---|---|---|---|---|---|---|
| 1999 | EARLY | MA | 0 | 0 | 0.2 | 0.0 | 0 | 0.00 | 0 |
| | | RI | 0 | 0 | 18.3 | 0.0 | 2 | 0.78 | 2.55 |
| | | CT | 0 | 0 | 2.7 | 0.0 | 1 | 0.94 | 1.06 |
| | | NY | 0 | 0 | 39.3 | 0.0 | 10 | 17.74 | 0.56 |
| | | NJ | 0 | 0 | 115.3 | 0.0 | 48 | 188.49 | 0.25 |
| | | DE | 335 | 4256 | 163.8 | 26.0 | 96 | 88.28 | 1.09 |
| | | MD | 1 | 43 | 28.5 | 1.5 | 20 | 28.26 | 0.71 |
| | | VA | 159 | 1182 | 345.6 | 3.4 | 56 | 93.43 | 0.60 |
| | | NC | 309 | 9995 | 991.4 | 10.1 | 135 | 33.55 | 4.02 |
| | | SC | 0 | 0 | 0.3 | 0.0 | 1 | 0.27 | 3.73 |
| | | GA | 102 | 0 | 0.3 | 0.0 | 0 | 0.00 | 0 |
| | | FL | 0 | 43 | 4.5 | 9.6 | 7 | 17.01 | 0.41 |
| | SEAMAP | SURVEY | 229 | | | | | | |
| | | TOTAL | **1,135** | **15,519** | **1,710** | **9.1** | **376** | **468.8** | **0.80** |
| 1999 | LATE | MA | 0 | 0 | 1 | 0.0 | 0 | 0.00 | 0.00 |
| | | RI | 0 | 0 | 38.9 | 0.0 | 2 | 1.88 | 1.06 |
| | | CT | 0 | 0 | 7.5 | 0.0 | 2 | 1.95 | 1.03 |
| | | NY | 0 | 0 | 182.8 | 0.0 | 15 | 10.86 | 1.38 |
| | | NJ | 0 | 0 | 470.4 | 0.0 | 152 | 434.84 | 0.35 |
| | | DE | 0 | 70 | 36.3 | 1.9 | 134 | 131.34 | 1.02 |
| | | MD | 226 | 556 | 72.7 | 7.6 | 242 | 218.71 | 1.11 |
| | | VA | 374 | 2128 | 414.2 | 5.1 | 61 | 87.82 | 0.69 |
| | | NC | 348 | 5752 | 186.5 | 30.8 | 123 | 39.61 | 3.11 |
| | | SC | 0 | 0 | 0 | | 3 | 1.72 | 1.74 |
| | | GA | 129 | 0 | 0 | | 2 | 0.73 | 2.73 |
| | | FL | 10 | 13 | 3.5 | 3.7 | 81 | 27.65 | 2.93 |
| | SEAMAP | SURVEY | 255 | | | | | | |
| | NEFSC | SURVEY | 373 | | | | | | |
| | | **TOTAL** | **1,715** | **8,519** | **1,414** | **6.0** | **817** | **957** | **0.85** |
| 2000 | EARLY | MA | 0 | 0 | 0.0 | | 0 | 0.00 | 0.00 |
| | | RI | 0 | 46 | 17.1 | 2.7 | 1 | 0.87 | 1.15 |
| | | CT | 0 | 0 | 1.0 | 0.0 | 3 | 2.92 | 1.03 |
| | | NY | 0 | 0 | 57.8 | 0.0 | 7 | 59.53 | 0.12 |
| | | NJ | 0 | 0 | 173.5 | 0.0 | 45 | 299.31 | 0.15 |
| | | DE | 481 | 1995 | 106.8 | 18.7 | 54 | 177.02 | 0.31 |
| | | MD | 113 | 113 | 22.4 | 5.0 | 22 | 31.05 | 0.71 |
| | | VA | 165 | 1219 | 258.8 | 0.0 | 117 | 142.25 | 0.82 |
| | | NC | 424 | 11816 | 608.7 | 4.8 | 51 | 18.80 | 2.71 |
| | | SC | 0 | 0 | 0.0 | | 0 | 0.00 | 0.00 |
| | | GA | 0 | 0 | 0.0 | | 1 | 0.20 | 5.13 |
| | | FL | 25 | 25 | 1.9 | 4.8 | 47 | 24.12 | 1.95 |
| | SEAMAP | SURVEY | | | | | | | |
| | | **TOTAL** | **1,208.0** | **15,214.0** | **1,248.0** | **12.2** | **348.0** | **756.1** | **0.46** |
| 2000 | LATE | MA | 0 | 0 | 0.0 | | 0 | 0.00 | 0.00 |
| | | RI | 0 | 132 | 58.6 | 2.3 | 0 | 0.00 | 0.00 |
| | | CT | 0 | 0 | 2.2 | 0.0 | 12 | 13.00 | 0.92 |
| | | NY | 0 | 0 | 76.3 | 0.0 | 2 | 15.10 | 0.13 |
| | | NJ | 0 | 0 | 312.4 | 0.0 | 132 | 569.83 | 0.23 |
| | | DE | 965 | 224 | 21.1 | 10.6 | 20 | 111.17 | 0.18 |
| | | MD | 99 | 99 | 60.7 | 1.6 | 221 | 284.95 | 0.78 |
| | | VA | 390 | 1885 | 365.7 | 5.2 | 77 | 82.83 | 0.93 |
| | | NC | 192 | 6426 | 232.4 | 27.7 | 71 | 21.08 | 3.37 |
| | | SC | | | | | 9 | 2.86 | 3.14 |
| | | GA | | | | | 3 | 1.40 | 2.15 |
| | | FL | | 0 | 2.1 | 0.0 | 29 | 26.33 | 1.10 |
| | SEAMAP | SURVEY | | | | | | | |
| | NEFSC | SURVEY | | | | | | | |
| | | **TOTAL** | | **8,766.0** | **1,131.5** | **7.7** | **576.0** | **1,128.6** | **0.5** |

Table 2A, continued

| YEAR | SEASON | STATE | AGED | MEASURED FROM COMM LANDINGS | COMM LANDINGS MT | COMM LENGTHS / MT | MEASURED FROM REC LANDINGS, MRFSS | RECREATIONAL LANDINGS, MT | REC LENGTHS / MT |
|---|---|---|---|---|---|---|---|---|---|
| 2001 | EARLY | MA | 0 | 0 | 0.0 | 0.0 | 0 | 0.00 | 0.00 |
| | | RI | 178** | 178** | 10.8 | 16.5 | 0 | 0.00 | 0.00 |
| | | CT | 34 | 0 | 0.3 | 0.0 | 0 | 0.00 | 0.00 |
| | | NY | 0 | 0 | 39.9 | 0.0 | 9 | 39.04 | 0.23 |
| | | NJ | 0 | 0 | 108.0 | 0.0 | 43 | 114.82 | 0.37 |
| | | DE | 300 | 370 | 75.0 | 4.9 | 69 | 50.69 | 1.36 |
| | | MD | 0 | 8 | 27.3 | 0.3 | 5 | 15.61 | 0.32 |
| | | VA | 152 | 758 | 249.9 | 3.0 | 82 | 107.63 | 0.76 |
| | | NC | 328 | 9,747 | 723.3 | 13.5 | 19 | 2.44 | 7.78 |
| | | SC | | | | | 0 | 0.00 | 0.00 |
| | | GA | | | 0.0 | | 1 | 0.12 | 8.06 |
| | | FL | | 0 | 2.4 | 0.0 | 6 | 10.42 | 0.58 |
| | SEAMAP | SURVEY | 99 | na | na | | na | | |
| | | **TOTAL** | **992** | **11,306** | **1,237** | **9.1** | **234** | **341** | **0.7** |
| 2001 | LATE | MA | 0 | 0 | 0.1 | 0.0 | 0 | 0.00 | 0.00 |
| | | RI | 178** | 178** | 38.9 | 4.6 | 0 | 0.00 | 0.00 |
| | | CT | 69 | 0 | 2.7 | 0.0 | 1 | 2.22 | 0.45 |
| | | NY | 0 | 372*** | 222.9 | 1.7 | 3 | 29.72 | 0.10 |
| | | NJ | 0 | 0 | 271.8 | 0.0 | 362 | 452.70 | 0.80 |
| | | DE | 861 | 0 | 2.7 | 0.0 | 59 | 27.77 | 2.12 |
| | | MD | 193 | 261 | 68.2 | 2.8 | 294 | 241.87 | 1.22 |
| | | VA | 420 | 1806 | 280.6 | 6.4 | 106 | 61.66 | 1.72 |
| | | NC | 220 | 3199 | 158.8 | 21.6 | 161 | 69.42 | 2.32 |
| | | SC | | | | | 0 | 0.00 | 0.00 |
| | | GA | | | | | 2 | 1.22 | 1.64 |
| | | FL | | 0 | 2.5 | 0.0 | 17 | 7.63 | 2.23 |
| | SEAMAP | SURVEY | 151 | na | na | | na | | |
| | NEFSC | SURVEY | 617 | na | na | | na | | |
| | | **TOTAL** | **2,699** | **6,003** | **1,049.3** | **5.7** | **1,005** | **894** | **1.1** |
| 2002 | EARLY | MA | 0 | 0 | 0.2 | 0.0 | 0 | 0.00 | 0.00 |
| | | RI | 50 | 50 | 30.4 | 1.6 | 0 | 0.00 | 0.00 |
| | | CT | 22 | 0 | 2.6 | 0.0 | 0 | 0.00 | 0.00 |
| | | NY | 0 | 0 | 45.0 | 0.0 | 4 | 9.48 | 0.42 |
| | | NJ | 0 | 0 | 92.4 | 0.0 | 101 | 228.98 | 0.44 |
| | | DE | 561 | 1,179 | 54.9 | 21.5 | 201 | 81.06 | 2.48 |
| | | MD | 20 | 21 | 11.0 | 1.9 | 12 | 10.80 | 1.11 |
| | | VA | 328 | 2,399 | 325.8 | 7.4 | 110 | 39.92 | 2.76 |
| | | NC | 231 | 9,121 | 691.8 | 13.2 | 47 | 7.92 | 5.93 |
| | | SC | | | | | 0 | 0.18 | 0.00 |
| | | GA | | | | | 0 | 0.00 | 0.00 |
| | | FL | | 0 | 1.6 | 0.0 | 17 | 21.17 | 0.80 |
| | SEAMAP | SURVEY | 122* | na | na | | na | | |
| | CHESMAP | SURVEY | 141 | na | na | | na | | |
| | | **TOTAL** | **1,478** | **12,770** | **1,255.74** | **10.2** | **492** | **400** | **1.2** |
| 2002 | LATE | MA | 0 | 0 | 0.2 | 0.0 | 0 | 0.00 | 0.00 |
| | | RI | 0 | 0 | 25.2 | 0.0 | 2 | 1.72 | 1.16 |
| | | CT | 42 | 0 | 2.0 | 0.0 | 1 | 5.12 | 0.20 |
| | | NY | 0 | 0 | 188.1 | 0.0 | 8 | 17.11 | 0.47 |
| | | NJ | 0 | 0 | 299.0 | 0.0 | 164 | 321.67 | 0.51 |
| | | DE | 760 | 0 | 23.5 | 0.0 | 58 | 29.23 | 1.98 |
| | | MD | 44 | 216 | 44.8 | 4.8 | 58 | 68.16 | 0.85 |
| | | VA | 318 | 4170 | 211.2 | 19.7 | 141 | 94.08 | 1.50 |
| | | NC | 281 | 3642 | 130.8 | 27.8 | 59 | 29.61 | 1.99 |
| | | SC | | | | | 7 | 22.56 | 0.31 |
| | | GA | | | | | 1 | 0.31 | 3.22 |
| | | FL | | 0 | 1.1 | 0.0 | 21 | 5.66 | 3.71 |
| | SEAMAP | SURVEY | 153 | na | na | | na | | |
| | CHESMAP | SURVEY | 550 | na | na | | na | | |
| | NEFSC | SURVEY | 692 | na | na | | na | | |
| | | **TOTAL** | **2,838** | **8,028** | **925.9** | **8.7** | **520** | **595** | **0.9** |

Table 2A, continued

| YEAR | SEASON | STATE | AGED | MEASURED FROM COMM LANDINGS | COMM LANDINGS MT | COMM LENGTHS / MT | MEASURED FROM REC LANDINGS, MRFSS | RECREATIONAL LANDINGS, MT | REC LENGTHS / MT |
|---|---|---|---|---|---|---|---|---|---|
| 2003 | EARLY | MA | 0 | 0 | 0.2 | 0.0 | 0 | 0.00 | 0.00 |
| | | RI | 0 | 0 | 8.4 | 0.0 | 0 | 0.00 | 0.00 |
| | | CT | 4 | 0 | 4.6 | 0.0 | 0 | 0.00 | 0.00 |
| | | NY | 0 | 0 | 30.6 | 0.0 | 1 | 11.55 | 0.09 |
| | | NJ | 36 | 104 | 70.4 | 1.5 | 22 | 58.20 | 0.38 |
| | | DE | 580 | 944 | 38.4 | 24.6 | 14 | 4.77 | 2.94 |
| | | MD | 0 | 7 | 3.2 | 2.2 | 0 | 0.00 | 0.00 |
| | | VA | 350 | 1900 | 100.5 | 18.9 | 41 | 49.83 | 0.82 |
| | | NC | 269 | 5227 | 267.9 | 19.5 | 42 | 15.64 | 2.68 |
| | | SC | | | | | 0 | 0.00 | 0.00 |
| | | GA | | | | | 0 | 0.00 | 0.00 |
| | | FL | | 0 | 1.0 | 0.0 | 9 | 4.50 | 2.00 |
| | SEAMAP | SURVEY | 219* | na | na | | na | | |
| | CHESMAP | SURVEY | 78 | na | na | | na | | |
| | | **TOTAL** | **1500** | **8,182** | **525.2** | **15.6** | **129** | **144** | **0.9** |
| 2003 | LATE | MA | 0 | 0 | 0.0 | 0.0 | 1 | 0.40 | 2.53 |
| | | RI | 211 | 343 | 20.3 | 16.9 | 1 | 1.08 | 0.93 |
| | | CT | 22 | 0 | 0.3 | 0.0 | 1 | 1.60 | 0.62 |
| | | NY | 0 | 0 | 34.7 | 0.0 | 4 | 5.28 | 0.76 |
| | | NJ | 29 | 0 | 83.6 | 0.0 | 38 | 93.16 | 0.41 |
| | | DE | 372 | 0 | 3.1 | 0.0 | 23 | 21.48 | 1.07 |
| | | MD | 202 | 276 | 11.1 | 24.8 | 17 | 11.20 | 1.52 |
| | | VA | 323 | 2226 | 108.1 | 20.6 | 49 | 47.93 | 1.02 |
| | | NC | 220 | 3523 | 114.1 | 30.9 | 89 | 57.60 | 1.55 |
| | | SC | | | | | 2 | 1.95 | 1.02 |
| | | GA | | | | | 3 | 0.60 | 4.98 |
| | | FL | | 0 | 0.2 | 0.0 | 13 | 5.56 | 2.34 |
| | SEAMAP | SURVEY | 0 | na | na | | na | | |
| | CHESMAP | SURVEY | 595* | na | na | | na | | |
| | NEFSC | SURVEY | 0 | | | | | | |
| | | **TOTAL** | **1975** | **6368** | **375.5** | **17.0** | **241** | **247.9** | **1.0** |

* MANY AGED WERE AGE 0

**EARLY AND LATE SEASONS POOLED

***NMFS AT-SEA OBSERVER DATA FROM NY-BASED TRAWLS

Table 3. Results of catch curve analysis of the four age-structured research trawl surveys. Each year class represented in each survey was subjected to catch curve analysis. For each survey, the table presents the number of ages represented for each year class, the statistical probability that the linear regression is due to chance alone and the resulting estimate of Z. Entries in bold are year classes present in the terminal year of the survey when they function as tuning indices in the estimation of stock size in the terminal year plus one. Estimates of Z that are negative are highlighted. Negative Z indicates a cohort gained animals instead of lost them as time proceeded, because the catch curve has a positive slope. These results are biologically nonsensical, and are grounds for disqualifying a survey if those year classes are present in the terminal year.

| | NEFSC | | | NEW JERSEY | | | DELAWARE | | | SEAMAP | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YEAR CLASS | NUMBER OF AGES | *P* | Z | NUMBER OF AGES | *P* | Z | NUMBER OF AGES | *P* | Z | NUMBER OF AGES | *P* | Z |
| 1981 | 4 | *ns* | 0.81 | | | | | | | | | |
| 1982 | 4 | *ns* | 0.57 | | | | | | | | | |
| 1983 | 4 | 0.02 | 0.94 | | | | | | | | | |
| 1984 | 4 | 0.083 | 1.83 | | | | | | | | | |
| 1985 | 4 | 0.13 | 1.5 | | | | | | | | | |
| 1986 | 4 | *ns* | 0.54 | | | | | | | | | |
| 1987 | 4 | *ns* | 0.43 | | | | | | | | | |
| 1988 | 4 | 0.055 | 1.37 | 6 | 0.003 | 1.09 | | | | | | |
| 1989 | 4 | 0.016 | 1.59 | 6 | 0.019 | 1.76 | | | | | | |
| 1990 | 4 | 0.023 | 1.7 | 6 | 0.009 | 1.06 | 6 | 0.003 | 1.12 | 4 | 0.104 | 2.01 |
| 1991 | 4 | 0.067 | 0.9 | 6 | 0.096 | 0.37 | 6 | 0.027 | 0.70 | 4 | *ns* | 0.42 |
| 1992 | 4 | *ns* | 0.57 | 6 | *ns* | 0.29 | 6 | 0.009 | 0.78 | 4 | *ns* | 0.72 |
| 1993 | 4 | *ns* | -0.12 | 6 | 0.047 | 0.77 | 6 | 0.02 | 0.56 | 4 | 0.024 | 2.14 |
| 1994 | 4 | 0.076 | 1.18 | 6 | 0.0035 | 0.74 | 6 | 0.0004 | 0.88 | 4 | 0.12 | 1.48 |
| 1995 | 4 | 0.013 | 1.43 | 6 | 0.0005 | 0.95 | 6 | 0.0045 | 1.23 | 4 | *ns* | 0.35 |
| 1996 | 4 | 0.102 | 0.82 | 6 | 0.037 | 0.75 | 6 | 0.013 | 1.51 | 4 | 0.11 | 1.79 |
| 1997 | 4 | *ns* | -0.06 | 6 | 0.075 | 0.66 | **6** | **0.18** | **1.49** | 4 | *ns* | 1.23 |
| 1998 | 4 | 0.053 | 0.6 | **6** | *ns* | **0.51** | **5** | **0.062** | **1.90** | 4 | 0.10 | 2.18 |
| 1999 | 4 | 0.13 | 0.63 | **5** | **0.053** | **0.60** | **4** | **0.11** | **1.68** | 4 | *ns* | 1.13 |
| 2000 | **4** | ***ns*** | **0.38** | **4** | **0.079** | **-1.80** | **3** | ***ns*** | **1.19** | **4** | **0.04** | **1.34** |
| 2001 | **3** | **0.08** | **-0.52** | **3** | ***ns*** | **0.10** | **2** | **--** | **Pos. Z** | **3** | ***ns*** | **0.91** |
| 2002 | **2** | **--** | **Neg. Z** | **2** | **--** | **Pos. Z** | | | | **2** | **--** | **Pos Z** |

Table 4. Commercial discard at age matrix for Mid-Atlantic based on a reduced suite of target species by year for all gears combined using the NMFS web site non-seasonal landings. This is table 47 in de Silva (2004).

| Year | Age 0 | Age 1 | Age 2 | Age 3 | Age 4 | Age 5 | Age 6+ | Total |
|---|---|---|---|---|---|---|---|---|
| 1973 | 496,272 | 1,798,471 | 432,026 | 10,992 | 1,353 | 328 | 63 | 2,739,505 |
| 1974 | 358,872 | 1,276,077 | 537,044 | 97,007 | 29,789 | 6,756 | 1,310 | 2,306,855 |
| 1975 | 327,205 | 1,675,847 | 477,224 | 128,566 | 34,446 | 7,857 | 1,529 | 2,652,674 |
| 1976 | 398,670 | 1,794,891 | 838,439 | 139,509 | 41,493 | 9,461 | 1,845 | 3,224,308 |
| 1977 | 118,146 | 857,487 | 815,590 | 138,242 | 21,875 | 6,298 | 52 | 1,957,690 |
| 1978 | 530,594 | 1,726,687 | 1,030,398 | 115,699 | 2,054 | 404 | 65 | 3,405,901 |
| 1979 | 1,405,045 | 2,936,122 | 1,205,998 | 179,724 | 75,242 | 17,090 | 3,314 | 5,822,535 |
| 1980 | 432,452 | 2,474,408 | 1,490,736 | 204,834 | 52,510 | 15,268 | 278 | 4,670,486 |
| 1981 | 1,119,410 | 2,150,565 | 1,139,045 | 242,816 | 4,434 | 899 | 117 | 4,657,286 |
| 1982 | 1,231,231 | 2,020,770 | 1,173,279 | 54,421 | 4,153 | 1,405 | 270 | 4,485,529 |
| 1983 | 338,196 | 1,573,161 | 769,150 | 120,319 | 4,590 | 1,090 | 204 | 2,806,710 |
| 1984 | 1,431,711 | 2,911,017 | 844,951 | 83,804 | 5,562 | 1,335 | 303 | 5,278,683 |
| 1985 | 664,091 | 1,363,018 | 572,220 | 112,636 | 5,630 | 1,315 | 260 | 2,719,170 |
| 1986 | 339,109 | 1,578,321 | 778,022 | 127,113 | 7,668 | 1,799 | 328 | 2,832,360 |
| 1987 | 226,608 | 1,279,953 | 809,783 | 93,259 | 6,879 | 1,685 | 356 | 2,418,523 |
| 1988 | 66,507 | 1,209,939 | 698,020 | 89,845 | 34,294 | 8,202 | 1,505 | 2,108,312 |
| 1989 | 434,524 | 1,459,189 | 508,949 | 27,032 | 4,681 | 1,125 | 233 | 2,435,733 |
| 1990 | 107,696 | 615,116 | 353,646 | 81,365 | 4,603 | 957 | 168 | 1,163,551 |
| 1991 | 112,805 | 692,218 | 365,542 | 64,104 | 18,979 | 4,420 | 914 | 1,258,982 |
| 1992 | 280,006 | 873,586 | 364,007 | 35,170 | 3,343 | 815 | 159 | 1,557,086 |
| 1993 | 126,917 | 1,205,400 | 586,812 | 53,935 | 5,533 | 1,179 | 207 | 1,979,983 |
| 1994 | 219,550 | 378,474 | 934,132 | 355,722 | 127,660 | 2,953 | 945 | 2,019,436 |
| 1995 | 810,598 | 576,647 | 421,332 | 125,037 | 42,341 | 1,329 | 455 | 1,977,739 |
| 1996 | 1,026,321 | 643,909 | 403,408 | 608,121 | 138,314 | 28,882 | 1,418 | 2,850,373 |
| 1997 | 81,776 | 488,903 | 550,869 | 229,738 | 318,110 | 35,324 | 8,578 | 1,713,298 |
| 1998 | 262,115 | 300,532 | 296,292 | 309,302 | 79,709 | 70,208 | 26,904 | 1,345,062 |
| 1999 | 2,347,445 | 416,099 | 104,082 | 123,654 | 183,637 | 15,922 | 15,080 | 3,205,919 |
| 2000 | 766 | 224,967 | 453,005 | 276,424 | 84,084 | 27,765 | 3,605 | 1,070,616 |
| 2001 | 1,872,576 | 342,137 | 432,406 | 201,192 | 86,170 | 17,497 | 10,359 | 2,962,337 |
| 2002 | 1,739,612 | 747,214 | 153,041 | 75,843 | 16,362 | 5,765 | 1,809 | 2,739,646 |

Table 5. The catch-at-age matrix through 2003, including commercial and recreational harvest and discards.

| | 1 | 2 | 3 | 4 | 5 | 6+ |
|---|---|---|---|---|---|---|
| 1982 | 9,914 | 12,967 | 5,473 | 2,778 | 722 | 639 |
| 1983 | 8,004 | 12,869 | 5,823 | 2,780 | 568 | 424 |
| 1984 | 10,444 | 14,737 | 6,521 | 3,045 | 485 | 255 |
| 1985 | 14,153 | 11,262 | 3,246 | 1,171 | 213 | 55 |
| 1986 | 18,611 | 15,778 | 4,942 | 1,824 | 264 | 52 |
| 1987 | 16,256 | 14,343 | 4,347 | 1,485 | 145 | 11 |
| 1988 | 8,162 | 16,141 | 10,545 | 6,092 | 1,051 | 71 |
| 1989 | 3,705 | 5,305 | 4,334 | 2,922 | 626 | 85 |
| 1990 | 9,510 | 4,890 | 2,094 | 1,205 | 591 | 89 |
| 1991 | 9,796 | 5,826 | 2,750 | 1,374 | 463 | 57 |
| 1992 | 5,179 | 6,046 | 2,211 | 1,255 | 528 | 65 |
| 1993 | 4,975 | 6,357 | 2,180 | 1,139 | 401 | 48 |
| 1994 | 3,544 | 3,810 | 3,357 | 1,490 | 202 | 39 |
| 1995 | 4,047 | 3,517 | 3,504 | 1,617 | 197 | 54 |
| 1996 | 2,126 | 2,456 | 4,682 | 3,094 | 1,363 | 99 |
| 1997 | 1,459 | 2,104 | 2,792 | 5,355 | 1,505 | 406 |
| 1998 | 1,136 | 2,005 | 3,844 | 1,983 | 2,897 | 897 |
| 1999 | 1,221 | 1,252 | 2,200 | 3,241 | 718 | 1,138 |
| 2000 | 1,159 | 1,499 | 1,939 | 1,838 | 1,851 | 466 |
| 2001 | 549 | 2,279 | 1,255 | 819 | 431 | 370 |
| 2002 | 1,142 | 700 | 2,451 | 808 | 391 | 217 |
| 2003 | 857 | 1,066 | 742 | 554 | 104 | 130 |

Table 6. Catch curve analysis results for the catch at age matrix, analysed by year class. Number of ages indicates the number of ages used in the regression, *P* indicates the statistical significance of the regression, $R^2$ indicates the proportion of variance explained and F value is the F statistic of the regression. Note that Fishing mortality = Z - M, where M = 0.25. 1993 data was not amenable to catch curve analysis, because the modal age was too old.

| Year Class | # Ages | Z | Fishing Mortality | P | $R^2$ | F value |
|---|---|---|---|---|---|---|
| 1982 | 3 | 1.55 | 1.30 | 0.22 | 0.77 | 7.59 |
| 1983 | 3 | 0.77 | 0.52 | 0.20 | 0.82 | 9.82 |
| 1984 | 3 | 0.97 | 0.72 | 0.42 | 0.25 | 1.65 |
| 1985 | 4 | 1.08 | 0.83 | 0.04 | 0.90 | 26.87 |
| 1986 | 4 | 1.19 | 0.94 | 0.002 | 0.99 | 389.89 |
| 1987 | 4 | 0.73 | 0.48 | 0.001 | 0.97 | 98.79 |
| 1988 | 3 | 0.96 | 0.71 | 0.068 | 0.98 | 87.57 |
| 1989 | 4 | 1.07 | 0.82 | 0.020 | 0.94 | 48.57 |
| 1990 | 4 | 1.06 | 0.81 | 0.042 | 0.88 | 22.20 |
| 1991 | 3 | 0.45 | 0.20 | 0.219 | 0.77 | 7.78 |
| 1992 | 4 | 0.29 | 0.04 | 0.115 | 0.68 | 7.25 |
| 1993 | - | - | | | | |
| 1994 | 8 | 0.96 | 0.71 | 0.0003 | 0.89 | 57.61 |
| 1995 | 5 | 1.40 | 1.15 | 0.002 | 0.96 | 90.48 |
| 1996 | 4 | 1.31 | 1.06 | 0.006 | 0.98 | 159.89 |
| 1997 | 3 | 1.51 | 1.26 | 0.174 | 0.85 | 12.77 |
| 1998 | 3 | 1.26 | 1.01 | 0.220 | 0.77 | 7.69 |

Table 7. Estimates of F, instantaneous fishing mortality by age and year from Gulland's cohort analysis
performed on the catch at age matrix.

| | AGE | | | | | | |
|---|---|---|---|---|---|---|---|
| **YEAR** | 1 | 2 | 3 | 4 | 5 | 6+ | FULLY-RECRUITED F (average of ages 4 and 5) |
| 1982 | 0.29 | 0.70 | 0.81 | 1.24 | 0.88 | --- | 1.06 |
| 1983 | 0.25 | 0.79 | 0.86 | 1.60 | 1.04 | --- | 1.32 |
| 1984 | 0.31 | 1.07 | 1.47 | 2.24 | 2.08 | --- | 2.16 |
| 1985 | 0.29 | 0.70 | 0.79 | 1.47 | 1.45 | --- | 1.46 |
| 1986 | 0.36 | 0.66 | 0.84 | 1.95 | 2.95 | --- | 2.45 |
| 1987 | 0.42 | 0.55 | 0.40 | 0.71 | 0.98 | --- | 0.85 |
| 1988 | 0.44 | 1.05 | 1.16 | 2.00 | 2.39 | --- | 2.20 |
| 1989 | 0.23 | 0.62 | 1.02 | 1.50 | 1.89 | --- | 1.70 |
| 1990 | 0.51 | 0.56 | 0.58 | 1.01 | 2.22 | --- | 1.61 |
| 1991 | 0.50 | 0.75 | 0.78 | 1.05 | 1.90 | --- | 1.48 |
| 1992 | 0.21 | 0.71 | 0.78 | 1.17 | 2.27 | --- | 1.72 |
| 1993 | 0.19 | 0.46 | 0.65 | 1.46 | 2.20 | --- | 1.83 |
| 1994 | 0.10 | 0.23 | 0.51 | 1.53 | 1.39 | --- | 1.46 |
| 1995 | 0.23 | 0.14 | 0.36 | 0.52 | 0.96 | --- | 0.74 |
| 1996 | 0.09 | 0.22 | 0.29 | 0.66 | 1.32 | --- | 0.99 |
| 1997 | 0.12 | 0.13 | 0.45 | 0.69 | 0.87 | --- | 0.78 |
| 1998 | 0.13 | 0.24 | 0.40 | 0.71 | 1.14 | --- | 0.92 |
| 1999 | 0.17 | 0.21 | 0.49 | 0.75 | 0.66 | --- | 0.71 |
| 2000 | 0.13 | 0.34 | 0.62 | 1.12 | 1.63 | --- | 1.37 |
| 2001 | 0.14 | 0.42 | 0.56 | 0.62 | 0.97 | --- | 0.79 |
| 2002 | 0.50 | 0.28 | 1.25 | 0.97 | 0.74 | --- | 0.85 |
| 2003 | --- | --- | --- | --- | --- | --- | |

Table 8. Stock size by year and age estimated by Gulland's Cohort Analysis of the catch at age matrix. Newton's method was used for the final estimates (Haddon 2001).

| | AGE | | | | | | |
|---|---|---|---|---|---|---|---|
| YEAR | 1 | 2 | 3 | 4 | 5 | 6+ | TOTAL 1 - 6+ |
| 1982 | 44,849 | 28,833 | 10,985 | 4,309 | 1,369 | 665 | 91010.2 |
| 1983 | 40,777 | 26,254 | 11,204 | 3,816 | 971 | 442 | 83464.2 |
| 1984 | 43,793 | 24,748 | 9,300 | 3,690 | 602 | 266 | 82399.5 |
| 1985 | 62,727 | 24,972 | 6,582 | 1,669 | 305 | 59 | 96314.5 |
| 1986 | 69,393 | 36,470 | 9,676 | 2,315 | 299 | 56 | 118208.5 |
| 1987 | 53,490 | 37,783 | 14,701 | 3,260 | 257 | 12 | 109504.1 |
| 1988 | 25,546 | 27,472 | 16,944 | 7,655 | 1,250 | 75 | 78942.4 |
| 1989 | 20,487 | 12,777 | 7,488 | 4,129 | 803 | 90 | 45773.4 |
| 1990 | 26,468 | 12,709 | 5,341 | 2,096 | 719 | 94 | 47426.6 |
| 1991 | 28,034 | 12,330 | 5,643 | 2,338 | 593 | 61 | 49000.6 |
| 1992 | 30,535 | 13,299 | 4,553 | 2,013 | 638 | 69 | 51105.9 |
| 1993 | 32,680 | 19,241 | 5,112 | 1,631 | 489 | 51 | 59204.4 |
| 1994 | 43,206 | 21,090 | 9,443 | 2,088 | 296 | 42 | 76164.6 |
| 1995 | 22,418 | 30,535 | 13,087 | 4,431 | 354 | 58 | 70881.7 |
| 1996 | 27,043 | 13,914 | 20,695 | 7,130 | 2,043 | 105 | 70929.0 |
| 1997 | 14,991 | 19,193 | 8,684 | 12,021 | 2,866 | 423 | 58178.8 |
| 1998 | 10,849 | 10,394 | 13,100 | 4,328 | 4,715 | 931 | 44318.1 |
| 1999 | 8,910 | 7,452 | 6,339 | 6,846 | 1,650 | 1,180 | 32377.8 |
| 2000 | 10,829 | 5,868 | 4,706 | 3,020 | 2,522 | 661 | 27607.6 |
| 2001 | 4,789 | 7,416 | 3,260 | 1,980 | 771 | 386 | 18602.2 |
| 2002 | 3,257 | 3,248 | 3,787 | 1,447 | 830 | 228 | 12796.5 |
| 2003 | 878 | 1,542 | 1,917 | 845 | 429 | 307 | 5918.0 |

Table 9A. Summary of selected 1982-2003 ADAPT VPA runs for wekfish.

| | | 24 | 14 | 18 | 20 | 32 |
|---|---|---|---|---|---|---|
| Indices | | All Trawl Surveys | DE, SEAMAP surveys YOY Surveys | DE, SEAMAP surveys Rec. Harvest/Trip at age Total Rec Catch/trip | Rec. Harvest/Trip at age Total Rec Catch/trip | Rec. Harvest/Trip at age Total Rec Catch/trip |
| M | | constant 0.25 | constant 0.25 | constant 0.25 | constant 0.25 | constant 0.25 1982-1995 increasing 1995 - 2001 constant 2001-2003 M = 0.6 |
| Number of indices used | | 27 | 17 | 19 | 5 | 5 |
| MSR | | 1.29 | 1.192 | 1.445 | 0.687 | 0.87 |
| 2004 N; CV | | | | | | |
| | 1 | 68,477; 0.39 | 57,287; 0.0019 | 37922; 0.47 | not estimated | not estimated |
| | 2 | 50,912; 0.32 | 49,403; 0.0022 | 31,019; 0.40 | not estimated | not estimated |
| | 3 | 33,654; 0.29 | 35,203; 0.0031 | 16,599; 0.38 | 2227.8; 0.72 | 2629; 0.80 |
| | 4 | 11,775; 0.27 | 18,728; 0.0058 | 5,671; 0.39 | 258.3; 0.80 | 320; 0.86 |
| | 5 | 39,909; 0.18 | 60,381; 0.0018 | 8,741; 0.29 | 164.6; 0.76 | 127; 0.86 |
| 6+ | | 1,592; 1.18 | 3,163; 0 | 80; 0.12 | 64.1 0.85 | 73; 0.96 |
| 2003 F | | | | | | |
| | 1 | 0.1 | 0.02 | 0.02 | 0.19 | 0.17 |
| | 2 | 0.03 | 0.03 | 0.05 | 0.35 | 0.26 |
| | 3 | 0.05 | 0.03 | 0.1 | 1.24 | 0.96 |
| | 4 | 0.01 | 0.01 | 0.05 | 1.36 | 1.38 |
| | 5 | 0.06 | 0.04 | 0.12 | 1.59 | 1.41 |
| 6+ | | 0.06 | 0.04 | 0.12 | 1.59 | 1.41 |
| 2003 $F_{4-5}$ | | 0.03 | 0.03 | 0.09 | 1.48 | 1.39 |
| zero indices treated as | | 0.01 | 0.01 | missing | missing | missing |
| Method for full F year T | | Average Method | Average Method | Average Method | Average Method | Average Method |

Table 9B. Retrospective bias in four ADAPT runs: 24, 13, 18 and 20. Output estimates of F and SSB when only data through 1998 is input, and when data through 2003 is input and resulting per cent change in estimates.

| **RUN NUMBER:** | **24** | **14** | **18** | **20** |
|---|---|---|---|---|
| $F_{1998}$ with 1998 data | 0.10 | 0.10 | 0.30 | 2.05 |
| $SSB_{1998}$ with 2003 data | 59,102 | 85,561 | 36,482 | 5,468 |
| $F_{1998}$ with 2003 data | 0.43 | 0.36 | 0.64 | 0.70 |
| $SSB_{1998}$ with 2003 data | 22,599 | 27,551 | 14,156 | 12,674 |
| % change in $F_{1998}$ | +207 | +260 | +113 | -66 |
| % CHANGE IN $SSB_{1998}$ | -62 | -68 | -61 | +132 |

Table 9C. Comparison of biomass dynamic model sensitivity analyses: estimates of intrinsic rate (r) and unfished stock biomass (K, mt of 25 cm+ weakfish). Model is a general description of indices and treatments; Indices is the number of indices included in the sensitivity run, q's is the number of scalars estimated; and Discards indicates whether discard estimates were included with landings. NE = Northeast Fisheries Science Center Survey. All surveys use trawls. Regression coefficients were not calculated for every model.

| Model | Years | Indices | q's | Discards | $r^2$ | N | (SSQ/N)^0.5 | r | K |
|---|---|---|---|---|---|---|---|---|---|
| NE, DE, NJ Z transformed | 1981-2003 | 3 | 1 | No | 0.41 | 56 | 0.66 | 1.32 | 41912 |
| NE, DE, NJ Z transformed | 1981-2003 | 3 | 1 | Yes | | 56 | 0.49 | 1.35 | 39910 |
| Mean of NE, DE, NJ Z indices | 1981-2003 | 1 | 1 | No | 0.58 | 23 | 0.44 | 1.10 | 47260 |
| Mean of NE, DE, NJ Z indices | 1981-2003 | 1 | 1 | Yes | | 23 | 0.23 | 1.44 | 41950 |
| Multiple q's, NE, DE, NJ | 1981-2003 | 3 | 3 | No | 0.56 | 56 | 0.77 | 1.80 | 41912 |
| NEFSC | 1981-2003 | 1 | 1 | No | 0.41 | 23 | 0.78 | 0.83 | 53581 |
| NJ | 1989-2003 | 1 | 1 | No | 0.26 | 15 | 0.61 | 1.12 | 56889 |
| DE | 1990-2003 | 1 | 1 | No | 0.48 | 14 | 0.52 | 0.85 | 1.54E+08 |
| DE | 1981-1984, 1990-2003 | 1 | 1 | No | 0.33 | 18 | 0.51 | 0.33 | 251708 |
| DE, 2 q's for years | 1981-1984, 1990-2003 | 1 | 2 | No | 0.49 | 18 | 0.46 | 1.08 | 82043 |
| DE&NJ Z indices | 1981-2003 | 2 | 1 | No | 0.48 | 38 | 0.56 | 1.37 | 40850 |
| NE&NJ Z indices | 1981-2003 | 2 | 1 | No | | 41 | 0.54 | 1.34 | 35926 |
| NE&DE Z indices | 1981-2003 | 2 | 2 | No | | 33 | 0.65 | 1.35 | 36141 |
| NE, DE, NJ Z transformed | 1975-2003 | 3 | 1 | No | 0.33 | 64 | 0.36 | 0.33 | 38313 |

***TABLE 10. TOTAL HARV+DISCARDS (HARVDIS, mt), MID-ATLANTIC PRIVATE BOAT FISHING EFFORT (TRIPS * 1000),MID-ATLANTIC PRIVATE BOAT REC CATCH (MIDHARV2,MT), PRIVATE BOAT CPUE (RelWt)***
***AND RelWt+1 IN T+1, AVERAGE AVRelWt IN YEARS T AND T+1, RELATIVE F AND SCALED FWt AND BIOMASS WEIGHTED M (MWt), 1982-2005***

| YEAR | HARVDIS | teffort | midharv2 | RelWt | relwt1 | avrelwt | RelFwt | FWt | MWt |
|---|---|---|---|---|---|---|---|---|---|
| 1982 | 13823 | 6028 | 2805.90 | 0.46548 | 0.50041 | 0.48294 | 28622.46 | 0.40644 | 0.57 |
| 1983 | 14426 | 8472 | 4239.46 | 0.50041 | 0.31305 | 0.40673 | 35468.49 | 0.50365 | 0.67 |
| 1984 | 13338 | 7881 | 2467.12 | 0.31305 | 0.27831 | 0.29568 | 45110.00 | 0.64056 | 0.82 |
| 1985 | 11181 | 6994 | 1946.49 | 0.27831 | 0.41802 | 0.34816 | 32114.40 | 0.45602 | 0.49 |
| 1986 | 15590 | 10003 | 4181.41 | 0.41802 | 0.35225 | 0.38513 | 40479.53 | 0.57481 | 0.44 |
| 1987 | 11691 | 8554 | 3013.15 | 0.35225 | 0.30444 | 0.32835 | 35605.73 | 0.50560 | 0.23 |
| 1988 | 13090 | 8862 | 2697.96 | 0.30444 | 0.12821 | 0.21633 | 60510.07 | 0.85924 | 0.64 |
| 1989 | 8136 | 6756 | 866.21 | 0.12821 | 0.08615 | 0.10718 | 75909.95 | 1.07792 | 0.01 |
| 1990 | 5440 | 7881 | 678.91 | 0.08615 | 0.10483 | 0.09549 | 56970.88 | 0.80899 | 0.06 |
| 1991 | 5610 | 8713 | 913.38 | 0.10483 | 0.13552 | 0.12017 | 46682.86 | 0.66290 | 0.34 |
| 1992 | 4793 | 6904 | 935.60 | 0.13552 | 0.08764 | 0.11158 | 42955.58 | 0.60997 | 0.39 |
| 1993 | 4448 | 8750 | 766.89 | 0.08764 | 0.18681 | 0.13723 | 32413.81 | 0.46028 | 0.33 |
| 1994 | 5395 | 9087 | 1697.51 | 0.18681 | 0.28561 | 0.23621 | 22840.19 | 0.32433 | 0.25 |
| 1995 | 5977 | 8581 | 2450.79 | 0.28561 | 0.37890 | 0.33226 | 17989.19 | 0.25545 | 0.22 |
| 1996 | 6879 | 8844 | 3351.02 | 0.37890 | 0.34514 | 0.36202 | 19001.69 | 0.26982 | 0.31 |
| 1997 | 7206 | 9725 | 3356.46 | 0.34514 | 0.44201 | 0.39357 | 18309.24 | 0.25999 | 0.37 |
| 1998 | 7809 | 8630 | 3814.51 | 0.44201 | 0.37756 | 0.40978 | 19056.48 | 0.27060 | 0.47 |
| 1999 | 6219 | 7935 | 2995.92 | 0.37756 | 0.41587 | 0.39671 | 15676.32 | 0.22260 | 0.56 |
| 2000 | 6126 | 11324 | 4709.30 | 0.41587 | 0.23894 | 0.32741 | 18710.67 | 0.26569 | 0.81 |
| 2001 | 5369 | 11982 | 2863.04 | 0.23894 | 0.23951 | 0.23923 | 22443.23 | 0.31869 | 0.61 |
| 2002 | 4434 | 9551 | 2287.53 | 0.23951 | 0.11906 | 0.17929 | 24731.48 | 0.35119 | 1.09 |
| 2003 | 2660 | 11286 | 1343.76 | 0.11906 | 0.05831 | 0.08869 | 29993.56 | 0.42591 | 0.76 |
| 2004 | 1483 | 11146 | 649.89 | 0.05831 | 0.10468 | 0.08150 | 18197.39 | 0.25840 | . |
| 2005 | 1937 | 11866 | 1242.18 | 0.10468 | . | . | 18503.36 | 0.26275 | . |

***TABLE 11. WEAKFISH AVERAGE BIOMASS (BIOt, MT) IN YEAR T, BIOMASS IN T+1 (BIOt+1, MT) TOTAL WEAKFISH HARVEST (HARVDIS) AND WEAKFISH SURPLUS PRODUCTION (SURPt),1982-2005 NOTE THAT SURPt ESTIMATE IN 2005 NOT POSSIBLE WITHOUT A 2006 BIOMASS ESTIMATE***

| YEAR | BIOt | BIOt1 | HARVDIS | SURPt |
|---|---|---|---|---|
| 1982 | 34010.03 | 28642.76 | 13823 | 8455.73 |
| 1983 | 28642.76 | 20822.34 | 14426 | 6605.58 |
| 1984 | 20822.34 | 24518.42 | 13338 | 17034.08 |
| 1985 | 24518.42 | 27122.04 | 11181 | 13784.62 |
| 1986 | 27122.04 | 23122.96 | 15590 | 11590.92 |
| 1987 | 23122.96 | 15234.34 | 11691 | 3802.38 |
| 1988 | 15234.34 | 7547.86 | 13090 | 5403.52 |
| 1989 | 7547.86 | 6724.46 | 8136 | 7312.60 |
| 1990 | 6724.46 | 8462.86 | 5440 | 7178.39 |
| 1991 | 8462.86 | 7857.77 | 5610 | 5004.91 |
| 1992 | 7857.77 | 9663.76 | 4793 | 6598.99 |
| 1993 | 9663.76 | 16634.26 | 4448 | 11418.49 |
| 1994 | 16634.26 | 23398.25 | 5395 | 12158.99 |
| 1995 | 23398.25 | 25494.39 | 5977 | 8073.15 |
| 1996 | 25494.39 | 27716.32 | 6879 | 9100.93 |
| 1997 | 27716.32 | 28857.87 | 7206 | 8347.55 |
| 1998 | 28857.87 | 27937.54 | 7809 | 6888.67 |
| 1999 | 27937.54 | 23056.82 | 6219 | 1338.28 |
| 2000 | 23056.82 | 16846.89 | 6126 | -83.93 |
| 2001 | 16846.89 | 12625.75 | 5369 | 1147.86 |
| 2002 | 12625.75 | 6245.47 | 4434 | -1946.28 |
| 2003 | 6245.47 | 5739.10 | 2660 | 2153.63 |
| 2004 | 5739.10 | 7372.09 | 1483 | 3115.99 |
| 2005 | 7372.09 | . | 1937 | . |

## *TABLE 12. OBSERVED WEAKFISH JUVENILE INDICES FROM RHODE ISLAND TO THE SOUTH ATLANTIC*

| YCL | RI | CT | NY | NJ | DE | MD | VIMS | NC | SEA |
|---|---|---|---|---|---|---|---|---|---|
| 1982 | 9.80 | . | . | . | 6.0 | 0.24 | 6.0 | . | . |
| 1983 | 7.00 | . | . | . | 11.5 | 0.22 | 10.9 | . | . |
| 1984 | 5.70 | 1.00 | . | . | 4.5 | 1.30 | 10.9 | . | . |
| 1985 | 2.20 | 6.19 | . | . | 6.7 | 0.13 | 6.1 | . | . |
| 1986 | 6.20 | 13.16 | 1.5 | . | 9.3 | 1.70 | 37.0 | . | . |
| 1987 | 1.80 | 0.63 | 0.3 | . | 12.8 | 0.44 | 4.6 | . | . |
| 1988 | 3.20 | 3.49 | 0.3 | . | 5.8 | 0.40 | 17.8 | 12.1 | . |
| 1989 | 10.10 | 8.69 | 0.1 | 25.7 | 4.7 | 0.20 | 21.8 | 102.0 | . |
| 1990 | 2.80 | 5.56 | 0.6 | 43.4 | 11.1 | 0.20 | 21.3 | 14.2 | . |
| 1991 | 16.50 | 11.95 | 0.3 | 14.7 | 8.7 | 0.80 | 30.0 | 50.2 | 2.1 |
| 1992 | 24.00 | 3.05 | 4.4 | 27.1 | 20.1 | 0.50 | 15.3 | 37.0 | 0.9 |
| 1993 | 5.60 | 4.08 | 1.2 | 6.0 | 14.7 | 2.30 | 15.9 | 43.7 | 0.2 |
| 1994 | 5.70 | 11.19 | 0.4 | 23.9 | 14.8 | 1.10 | 15.4 | 8.7 | 15.3 |
| 1995 | 15.60 | 5.22 | 1.7 | 37.1 | 11.5 | 1.50 | 7.0 | 68.1 | 43.8 |
| 1996 | 2.20 | 15.23 | 0.9 | 77.5 | 13.5 | 6.10 | 11.0 | 38.2 | 3.6 |
| 1997 | 38.60 | 12.38 | 4.7 | 46.3 | 12.1 | 5.10 | 7.4 | 72.4 | 20.3 |
| 1998 | 25.80 | 5.02 | 2.7 | 21.8 | 15.4 | 7.30 | 14.8 | 32.8 | 0.7 |
| 1999 | 4.20 | 30.93 | 0.5 | 3.0 | 11.4 | 16.00 | 9.9 | 70.4 | 4.5 |
| 2000 | 0.01 | 63.31 | 2.2 | 25.3 | 13.5 | 2.10 | 16.3 | 100.0 | 24.5 |
| 2001 | 0.01 | 40.09 | 3.9 | 0.1 | 14.1 | 6.50 | 11.1 | 63.0 | 9.0 |
| 2002 | 0.30 | 41.35 | 3.2 | 21.7 | 7.6 | 7.50 | 11.5 | 30.3 | 5.6 |
| 2003 | 0.20 | 49.41 | 2.6 | 39.3 | 6.0 | 3.90 | 8.6 | 22.0 | 44.3 |
| 2004 | 3.10 | 58.98 | 1.4 | 72.7 | 10.9 | 1.80 | 5.4 | 23.9 | 22.2 |

***TABLE 13. JUVENILE INDICES SCALED IN MAGNITUDE TO THE NEW JERSEY INDICES WITH THE COASTWIDE MEAN JUVENILE INDEX (N0), THE AGE 1 INDEX (NIJ) AND THE JUVENILE MORTALITY (Z0) RATE***

| YCL | RI1 | CT1 | NY1 | NJ | DE1 | MD1 | VIMS1 | NC1 | SEA1 | N0 | N1J | Z0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1982 | 36.260 | . | . | . | 16.80 | 2.496 | 13.20 | . | . | 17.19 | 4.55556 | 1.32798 |
| 1983 | 25.900 | . | . | . | 32.20 | 2.288 | 23.98 | . | . | 21.09 | 4.90000 | 1.45956 |
| 1984 | 21.090 | 1.600 | . | . | 12.60 | 13.520 | 23.98 | . | . | 14.56 | 7.04444 | 0.72604 |
| 1985 | 8.140 | 9.904 | . | . | 18.76 | 1.352 | 13.42 | . | . | 10.32 | 7.87778 | 0.27004 |
| 1986 | 22.940 | 21.056 | 26.70 | . | 26.04 | 17.680 | 81.40 | . | . | 32.64 | 6.04444 | 1.68640 |
| 1987 | 6.660 | 1.008 | 5.34 | . | 35.84 | 4.576 | 10.12 | . | . | 10.59 | 2.92222 | 1.28757 |
| 1988 | 11.840 | 5.584 | 5.34 | . | 16.24 | 4.160 | 39.16 | 7.865 | . | 12.88 | 2.31111 | 1.71795 |
| 1989 | 37.370 | 13.904 | 1.78 | 25.7 | 13.16 | 2.080 | 47.96 | 66.300 | . | 23.14 | 2.96667 | 2.05412 |
| 1990 | 10.360 | 8.896 | 10.68 | 43.4 | 31.08 | 2.080 | 46.86 | 9.230 | . | 18.07 | 3.26667 | 1.71048 |
| 1991 | 61.050 | 19.120 | 5.34 | 14.7 | 24.36 | 8.320 | 66.00 | 32.630 | 4.41 | 26.21 | 3.92222 | 1.89948 |
| 1992 | 88.800 | 4.880 | 78.32 | 27.1 | 56.28 | 5.200 | 33.66 | 24.050 | 1.89 | 35.58 | 3.97778 | 2.19106 |
| 1993 | 20.720 | 6.528 | 21.36 | 6.0 | 41.16 | 23.920 | 34.98 | 28.405 | 0.42 | 20.39 | 5.31111 | 1.34524 |
| 1994 | 21.090 | 17.904 | 7.12 | 23.9 | 41.44 | 11.440 | 33.88 | 5.655 | 32.13 | 21.62 | 2.50000 | 2.15733 |
| 1995 | 57.720 | 8.352 | 30.26 | 37.1 | 32.20 | 15.600 | 15.40 | 44.265 | 91.98 | 36.99 | 3.18889 | 2.45098 |
| 1996 | 8.140 | 24.368 | 16.02 | 77.5 | 37.80 | 63.440 | 24.20 | 24.830 | 7.56 | 31.54 | 1.68889 | 2.92719 |
| 1997 | 142.820 | 19.808 | 83.66 | 46.3 | 33.88 | 53.040 | 16.28 | 47.060 | 42.63 | 53.94 | 1.11111 | 3.88251 |
| 1998 | 95.460 | 8.032 | 48.06 | 21.8 | 43.12 | 75.920 | 32.56 | 21.320 | 1.47 | 38.64 | 0.90000 | 3.75965 |
| 1999 | 15.540 | 49.488 | 8.90 | 3.0 | 31.92 | 166.400 | 21.78 | 45.760 | 9.45 | 39.14 | 1.18889 | 3.49413 |
| 2000 | 0.037 | 101.296 | 39.16 | 25.3 | 37.80 | 21.840 | 35.86 | 65.000 | 51.45 | 41.97 | 0.38889 | 4.68142 |
| 2001 | 0.037 | 64.144 | 69.42 | 0.1 | 39.48 | 67.600 | 24.42 | 40.950 | 18.90 | 36.12 | 0.71111 | 3.92777 |
| 2002 | 1.110 | 66.160 | 56.96 | 21.7 | 21.28 | 78.000 | 25.30 | 19.695 | 11.76 | 33.55 | 0.56667 | 4.08102 |
| 2003 | 0.740 | 79.056 | 46.28 | 39.3 | 16.80 | 40.560 | 18.92 | 14.300 | 93.03 | 38.78 | 0.56667 | 4.22589 |
| 2004 | 11.470 | 94.368 | 24.92 | 72.7 | 30.52 | 18.720 | 11.88 | 15.535 | 46.62 | 36.30 | . | . |

***TABLE 14. TIME SERIES OF ATL. CROAKER, TAG-BASED STRIPED BASS, VPA-BASED STRIPED BASS SUMMER FLOUNDER, SPINY DOGFISH AND BLUEFISH ABUNDANCE. AVERAGE ANNAUL WATER TEMPERATURE (LAGGED T-2)***
***AND DEVIATIONS IN THE NORTH ATL OSCILLATION INDEX (LAGGED T-2), 1982-2004.***

| YEAR | croak | STRIP | strip2 | FLUKE2 | SHK2 | BLUE2 | TEMP | NAO |
|---|---|---|---|---|---|---|---|---|
| 1982 | 361 | 1395 | 218 | 17.5 | 695 | 229.1 | 11.1 | 31 |
| 1983 | 4143 | 1619 | 253 | 17.5 | 250 | 212.5 | 11.0 | 112 |
| 1984 | 2597 | 1734 | 271 | 18.8 | 265 | 182.2 | 11.1 | 44 |
| 1985 | 3698 | 1498 | 234 | 16.1 | 1057 | 162.9 | 12.0 | 187 |
| 1986 | 4903 | 1734 | 271 | 15.0 | 278 | 170.3 | 12.0 | 87 |
| 1987 | 4828 | 1210 | 357 | 13.9 | 550 | 154.9 | 12.0 | -34 |
| 1988 | 4854 | 2849 | 348 | 14.4 | 708 | 119.6 | 11.9 | 27 |
| 1989 | 3400 | 3827 | 501 | 8.1 | 464 | 103.7 | 11.8 | -41 |
| 1990 | 6434 | 2075 | 997 | 5.2 | 939 | 91.8 | 11.1 | 39 |
| 1991 | 15348 | 1844 | 1278 | 7.5 | 547 | 83.7 | 11.3 | 277 |
| 1992 | 9401 | 1994 | 1840 | 6.0 | 736 | 71.2 | 12.1 | 216 |
| 1993 | 13542 | 2486 | 2022 | 7.3 | 566 | 72.0 | 12.6 | 56 |
| 1994 | 17127 | 4027 | 2373 | 9.2 | 515 | 67.0 | 11.5 | 179 |
| 1995 | 11599 | 3486 | 2832 | 12.0 | 461 | 67.7 | 11.7 | 146 |
| 1996 | 10973 | 5201 | 3129 | 15.6 | 769 | 65.6 | 11.6 | 165 |
| 1997 | 17522 | 4893 | 3606 | 15.9 | 516 | 64.7 | 12.5 | 216 |
| 1998 | 16569 | 3877 | 4120 | 15.7 | 355 | 70.7 | 10.6 | -206 |
| 1999 | 15952 | 4256 | 4072 | 17.8 | 480 | 73.0 | 10.9 | -11 |
| 2000 | 22407 | 8280 | 4592 | 16.5 | 355 | 80.3 | 12.1 | 39 |
| 2001 | 21186 | 9907 | 5960 | 19.4 | 305 | 87.7 | 12.9 | 93 |
| 2002 | 20772 | 13066 | 6621 | 25.5 | 472 | 88.2 | 12.2 | 153 |
| 2003 | 18773 | 13672 | 6056 | 29.4 | 469 | 92.2 | 12.5 | 49 |
| 2004 | 17600 | 17099 | 6712 | 36.7 | 225 | 104.1 | 12.7 | 112 |
| 2005 | . | . | . | . | . | . | . | . |

**Table 15. Three stepwise regression models with weakfish surplus production (SURPt), biomass weighted (ages 1+) natural mortality (MWt) and juvenile mortality (Z0) used as dependent variables. The independent variables included abundance of striped bass, bluefish, croaker, fluke and spiny dogfish as well as mean annual water temperature, deviations in the North Atlantic Oscillation Index and fishing mortality (FWt). Given below are the independent variables that were selected by the stepwise model. The slope (b) of the regression its standard error (SEb), Pearson correlation coefficient (r) and the probability (P) level for model fit are included.**

| | *Dependent Variables* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Significant Variable** | **SURPt** | | | | **MWt** | | | | **Z0** | | | |
| | **b** | **SEb** | **r** | **P** | **b** | **SEb** | **r** | **P** | **b** | **SEb** | **r** | **P** |
| **Strip** | **-0.83** | **0.21** | **-0.66** | **<0.001** | | | | | | | | |
| **Fluke** | | | | | **0.03** | **0.006** | **0.79** | **<0.0001** | | | | |
| **Strip2** | | | | | | | | | **0.0005** | **0.00005** | **0.91** | **<0.0001** |

**Table 16. Pearson correlation (r) matrix relating the three weakfish dependent variables (SURPT, MWt, Z0) with each of the nine potential explanatory variables. The P value indicates the level of statistical significance.**

| | *Dependent Variable* | | | | | |
|---|---|---|---|---|---|---|
| ***Explanatory Variable*** | **SURPt** | | **MWt** | | **Z0** | |
| | **r** | **P** | **r** | **P** | **r** | **P** |
| **Strip** | **-0.62** | **0.001*** | **0.55** | **0.009*** | **0.84** | **0.0001*** |
| **Strip2** | **-0.66** | **0.001*** | **0.44** | **0.04*** | **0.91** | **0.0001*** |
| **Fluke** | **-0.37** | **0.07** | **0.79** | **0.0001*** | **0.46** | **0.03*** |
| **Croaker** | **-0.60** | **0.003*** | **0.30** | **0.17** | **0.85** | **0.0001*** |
| **Bluefish** | **0.33** | **0.13** | **0.24** | **0.29** | **-0.61** | **0.002**** |
| **Spiny Dog** | **0.23** | **0.29** | **-0.36** | **0.10** | **-0.36** | **0.10** |
| **Temperature** | **-0.26** | **0.23** | **0.12** | **0.61** | **0.27** | **0.23** |
| **NAO** | **0.13** | **0.56** | **-0.002** | **0.99** | **-0.10** | **0.65** |
| **FWt** | **0.22** | **0.31** | **-0.32** | **0.14** | **-0.20** | **0.33** |

- *** indicates a statistically significant (P < 0.05) relationship with dependent variable.**
- **** indicates a statistically significant (P < 0.05) relationship with dependent variable but in the wrong direction.**

**Table 17. Parameter estimates (r, K) and weakfish overfishing thresholds (Fmsy, Fcoll, Bmsy) derived from the basic (see equation 7) Gompertz production model (no predation effects) fitted by nonlinear least squares and by iterative reweighting least squares, 1982-2004. The standard error (SE) is given for each parameter estimate, as well as the coefficient of determination (r**2).**

| | *Least Squares* | | *Iterative Reweighting* | |
|---|---|---|---|---|
| **Parameters** | **Mean** | **SE** | **Mean** | **SE** |
| **r** | **0.32** | **0.11** | **0.36** | **0.07** |
| **K** | **68,704 mt** | **25,618 mt** | **62,072 mt** | **11,989 mt** |
| **r**2** | **0.68** | | **0.82** | |
| | *Overfishing Thresholds* | | | |
| **Fmsy** | **0.32** | **0.11** | **0.36** | **0.07** |
| **Fcoll** | **0.87** | **0.30** | **0.98** | **0.19** |
| **Bmsy** | **25,259 mt** | **9,412 mt** | **22,821 mt** | **4,417 mt** |

***TABLE 18. OBSERVED AND PREDICTED WEAKFISH BIOMASS AND RESIDUALS FROM GOMPERTZ PRODUCTION MODEL WITH NO ITERATIVE REWEIGHTING***

| YEAR | BIOL | pred22 | RESID22 |
|---|---|---|---|
| 1982 | 28643 | 27664.87 | 978.13 |
| 1983 | 20822 | 21879.39 | -1057.39 |
| 1984 | 24518 | 14896.08 | 9621.92 |
| 1985 | 27122 | 20953.48 | 6168.52 |
| 1986 | 23123 | 19198.01 | 3924.99 |
| 1987 | 15234 | 18990.86 | -3756.86 |
| 1988 | 7548 | 8887.38 | -1339.38 |
| 1989 | 6724 | 4223.48 | 2500.52 |
| 1990 | 8463 | 5785.83 | 2677.17 |
| 1991 | 7858 | 7979.14 | -121.14 |
| 1992 | 9664 | 7986.35 | 1677.65 |
| 1993 | 16634 | 10713.85 | 5920.15 |
| 1994 | 23398 | 18196.42 | 5201.58 |
| 1995 | 25494 | 24993.03 | 500.97 |
| 1996 | 27716 | 26258.62 | 1457.38 |
| 1997 | 28858 | 28177.34 | 680.66 |
| 1998 | 27397 | 28709.05 | -1312.05 |
| 1999 | 23057 | 28847.07 | -5790.07 |
| 2000 | 16847 | 24486.57 | -7639.57 |
| 2001 | 12626 | 18465.05 | -5839.05 |
| 2002 | 6245 | 14438.58 | -8193.58 |
| 2003 | 5739 | 7894.16 | -2155.16 |
| 2004 | 7372 | 8350.52 | -978.52 |
| 2005 | 7372 | 10182.53 | -2810.53 |

***TABLE 19. OBSERVED AND PREDICTED WEAKFISH BIOMASS,RESIDUALS (RBI) AND WEIGHTING COEFFICENTS FROM GOMPERTZ PRODUCTION MODEL WITH ITERATIVE REWEIGHTING***

| YEAR | BIOL | pred11 | RBI | _WEIGHT_ |
|---|---|---|---|---|
| 1982 | 28643 | 27779.62 | 863.38 | 0.98168 |
| 1983 | 20822 | 22102.22 | -1280.22 | 0.95994 |
| 1984 | 24518 | 15228.40 | 9289.60 | 0.00000 |
| 1985 | 27122 | 21242.02 | 5879.98 | 0.32851 |
| 1986 | 23123 | 19446.97 | 3676.03 | 0.69417 |
| 1987 | 15234 | 19297.73 | -4063.73 | 0.63381 |
| 1988 | 7548 | 9252.63 | -1704.63 | 0.92954 |
| 1989 | 6724 | 4540.42 | 2183.58 | 0.88574 |
| 1990 | 8463 | 6088.12 | 2374.88 | 0.86559 |
| 1991 | 7858 | 8309.66 | -451.66 | 0.99497 |
| 1992 | 9664 | 8308.20 | 1355.80 | 0.95513 |
| 1993 | 16634 | 11058.38 | 5575.62 | 0.37971 |
| 1994 | 23398 | 18557.72 | 4840.28 | 0.50518 |
| 1995 | 25494 | 25296.45 | 197.55 | 0.99904 |
| 1996 | 27716 | 26533.12 | 1182.88 | 0.96575 |
| 1997 | 28858 | 28416.35 | 441.65 | 0.99519 |
| 1998 | 27397 | 28928.01 | -1531.01 | 0.94296 |
| 1999 | 23057 | 29091.47 | -6034.47 | 0.30298 |
| 2000 | 16847 | 24794.26 | -7947.26 | 0.04851 |
| 2001 | 12626 | 18825.48 | -6199.48 | 0.27616 |
| 2002 | 6245 | 14802.12 | -8557.12 | 0.00922 |
| 2003 | 5739 | 8186.74 | -2447.74 | 0.85753 |
| 2004 | 7372 | 8631.84 | -1259.84 | 0.96119 |
| 2005 | 7372 | 10496.55 | -3124.55 | 0.77347 |

**Table 20. Parameter estimates (r, K, c, A) and weakfish overfishing thresholds (Fmsy, Fcoll, Bmsy) derived from the Steele-Henderson Production Model (see equation 6) with striped bass predation effects fitted by nonlinear least squares and by iterative reweighting least squares, 1982-2004. The standard error (SE) is given for each parameter estimate, as well as the coefficient of determination (r**2).**

| | *Least Squares* | | *Iterative Reweighting* | |
|---|---|---|---|---|
| **Parameters** | **Mean** | **SE** | **Mean** | **SE** |
| **r** | **0.59** | **0.16** | **0.55** | **0.09** |
| **K** | **57,607 mt** | **13,620 mt** | **63,649 mt** | **11,683 mt** |
| **c** | **1.52** | **0.53** | **1.71** | **0.41** |
| **A** | **10,364 mt** | **3,966 mt** | **11,541 mt** | **3,406 mt** |
| **r**2** | | **0.88** | | **0.94** |
| | *Overfishing Thresholds* | | | |
| **Fmsy** | **0.59** | **0.16** | **0.55** | **0.09** |
| **Fcoll** | **1.60** | **0.43** | **1.50** | **0.25** |
| **Bmsy** | **21,179 mt** | **5,001 mt** | **23,400 mt** | **4,305 mt** |

***TABLE 21.OBSERVED AND PREDICTED WEAKFISH BIOMASS,RESIDUALS (RBI) AND REWEIGHTING COEFFICIENTS FROM STEELE-HENDERSON MODEL WITH STRIPED BASS AND ITERATIVE REWEIGHTING***

| YEAR | BIOL | pred11 | rbi | _WEIGHT_ |
|---|---|---|---|---|
| 1982 | 28643 | 29747.52 | -1104.52 | 0.95083 |
| 1983 | 20822 | 24388.75 | -3566.75 | 0.54815 |
| 1984 | 24518 | 17986.22 | 6531.78 | 0.01672 |
| 1985 | 27122 | 24078.38 | 3043.62 | 0.65763 |
| 1986 | 23123 | 21720.70 | 1402.30 | 0.92135 |
| 1987 | 15234 | 22626.86 | -7392.86 | 0.00000 |
| 1988 | 7548 | 11005.06 | -3457.06 | 0.57168 |
| 1989 | 6724 | 6284.94 | 439.06 | 0.99215 |
| 1990 | 8463 | 8680.47 | -217.47 | 0.99807 |
| 1991 | 7858 | 11122.99 | -3264.99 | 0.61222 |
| 1992 | 9664 | 11007.51 | -1343.51 | 0.92768 |
| 1993 | 16634 | 13462.74 | 3171.26 | 0.63164 |
| 1994 | 23398 | 18843.16 | 4554.84 | 0.33247 |
| 1995 | 25494 | 25479.17 | 14.83 | 0.99999 |
| 1996 | 27716 | 24037.78 | 3678.22 | 0.52402 |
| 1997 | 28858 | 26027.77 | 2830.23 | 0.69978 |
| 1998 | 27397 | 27863.24 | -466.24 | 0.99115 |
| 1999 | 23057 | 27675.86 | -4618.86 | 0.31879 |
| 2000 | 16847 | 18461.01 | -1614.01 | 0.89650 |
| 2001 | 12626 | 12240.82 | 385.18 | 0.99395 |
| 2002 | 6245 | 7231.76 | -986.76 | 0.96065 |
| 2003 | 5739 | 6248.72 | -509.72 | 0.98942 |
| 2004 | 7372 | 6039.48 | 1332.52 | 0.92884 |
| 2005 | 7372 | . | . | . |

***TABLE 22. WEAKFISH FISHING MORTALITY (FWt), PREDATOR NATURAL MORTALITY (MP) FROM EXPONENTS OF THE S-H MODEL AND NATURAL MORTALITY (MWt), 1982-2004***

| YEAR | FWT | MP | MWT |
|---|---|---|---|
| 1982 | 0.410 | 0.06828 | 0.57 |
| 1983 | 0.500 | 0.09630 | 0.67 |
| 1984 | 0.640 | 0.10006 | 0.82 |
| 1985 | 0.460 | 0.08121 | 0.49 |
| 1986 | 0.570 | 0.09993 | 0.44 |
| 1987 | 0.510 | 0.08637 | 0.23 |
| 1988 | 0.860 | 0.27173 | 0.64 |
| 1989 | 1.080 | 0.27474 | 0.01 |
| 1990 | 0.810 | 0.11842 | 0.06 |
| 1991 | 0.660 | 0.13512 | 0.34 |
| 1992 | 0.610 | 0.12328 | 0.39 |
| 1993 | 0.460 | 0.13325 | 0.33 |
| 1994 | 0.320 | 0.23224 | 0.25 |
| 1995 | 0.260 | 0.19613 | 0.22 |
| 1996 | 0.270 | 0.27743 | 0.31 |
| 1997 | 0.260 | 0.25208 | 0.37 |
| 1998 | 0.270 | 0.20320 | 0.47 |
| 1999 | 0.220 | 0.24501 | 0.56 |
| 2000 | 0.270 | 0.56747 | 0.81 |
| 2001 | 0.320 | 0.78241 | 0.61 |
| 2002 | 0.350 | 1.29008 | 1.09 |
| 2003 | 0.430 | 0.88369 | 0.76 |
| 2004 | 0.260 | 0.88427 | . |
| 2005 | 0.263 | . | . |

Table 23. Model conditions used for projections and to test for sensitivity. Starting model = Base 3 Parameter is the base model run where r?, K, and $B_{1981}$ were estimated simultaneously; Schaefer, Gompertz and Predator-prey used previous surplus production models as a starting point and held K constant (fixed). Recent F and Z are the two year averages for 2001-2002, with the exception of the 3 Parameter model with F fixed at values estimated in Crecco (2005); this run used the average for 2001-2003.

| Starting model | Base 3 Parameter | Crecco (2005) | Schaefer[1] | Gompertz[1] | Predator-prey[2] |
|---|---|---|---|---|---|
| F | Estimated | Fixed[1] | Estimated | Estimated | Estimated |
| K | Estimated | Estimated | Fixed | Fixed | Fixed |
| Estimated K (mt) | 86,409 | 86,409 | 57,700[1] | 64,028[1] | 49,500[2] |
| Estimated r? | 0.903 | 0.903 | 0.896 | 0.897 | 0.893 |
| Recent F | 0.41 | 0.35 | 0.41 | 0.41 | 0.41 |
| Recent Z | 1.36 | 1.39 | 1.43 | 1.38 | 1.42 |
| Recent F/Z | 0.30 | 0.25 | 0.28 | 0.29 | 0.29 |
| Z - (F*0.5) | 1.15 | 1.21 | 1.23 | 1.18 | 1.22 |
| Z - (F*1.0) | 0.95 | 1.04 | 1.02 | 0.98 | 1.02 |
| Z - (F*1.5) | 0.75 | 0.86 | 0.82 | 0.77 | 0.81 |
| Z - (F*2.0) | 0.54 | 0.69 | 0.62 | 0.57 | 0.61 |

**1 = Crecco (2005).**
**2= Uphoff (2005).**

## FIGURES

**Figure 1.**
**Total Weakfish Landings 1981-2004**

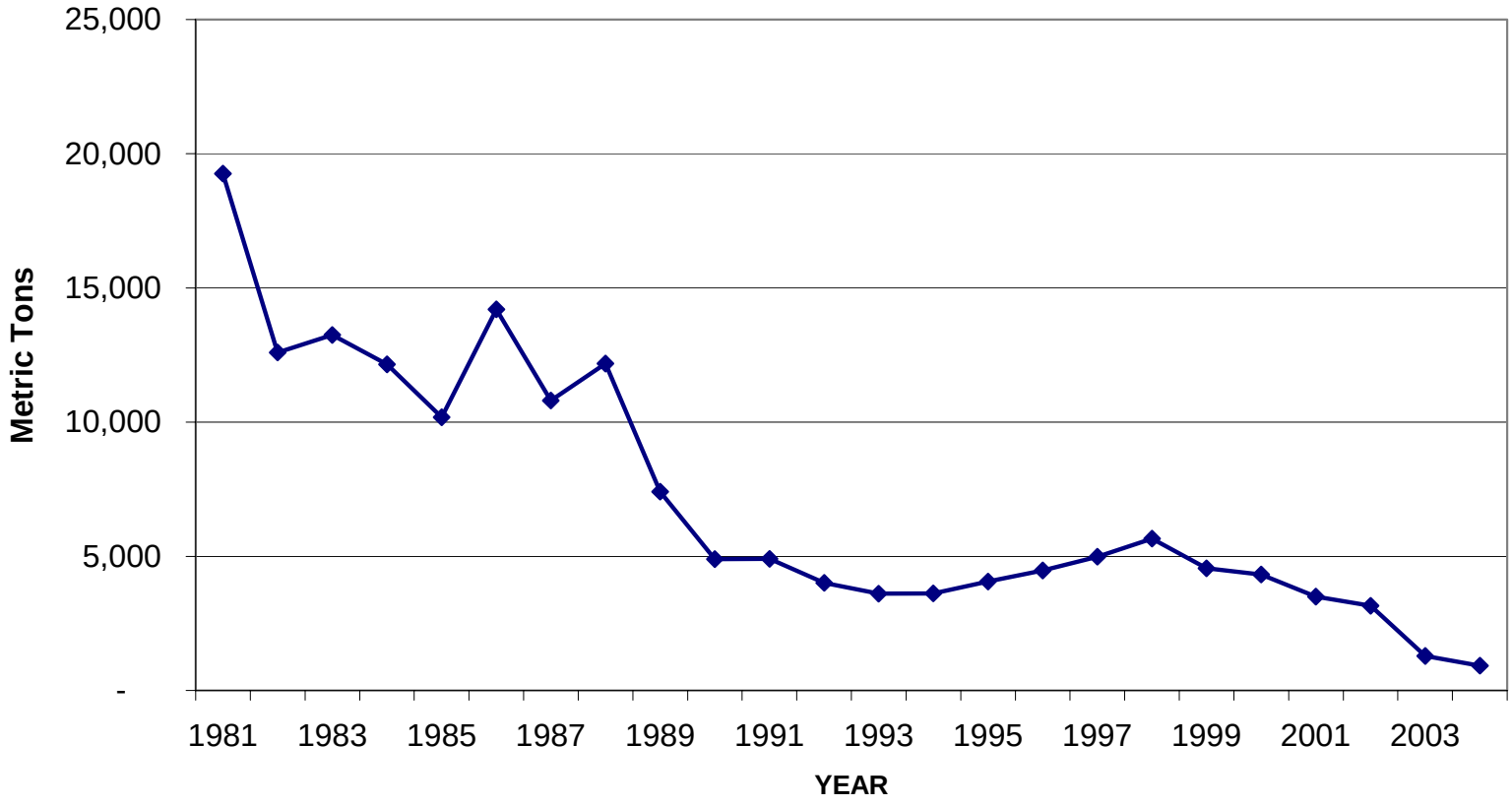


Figure 1A. Atlantic coast 1950-2003 commercial and 1981-2003 recreational landings of weakfsh.

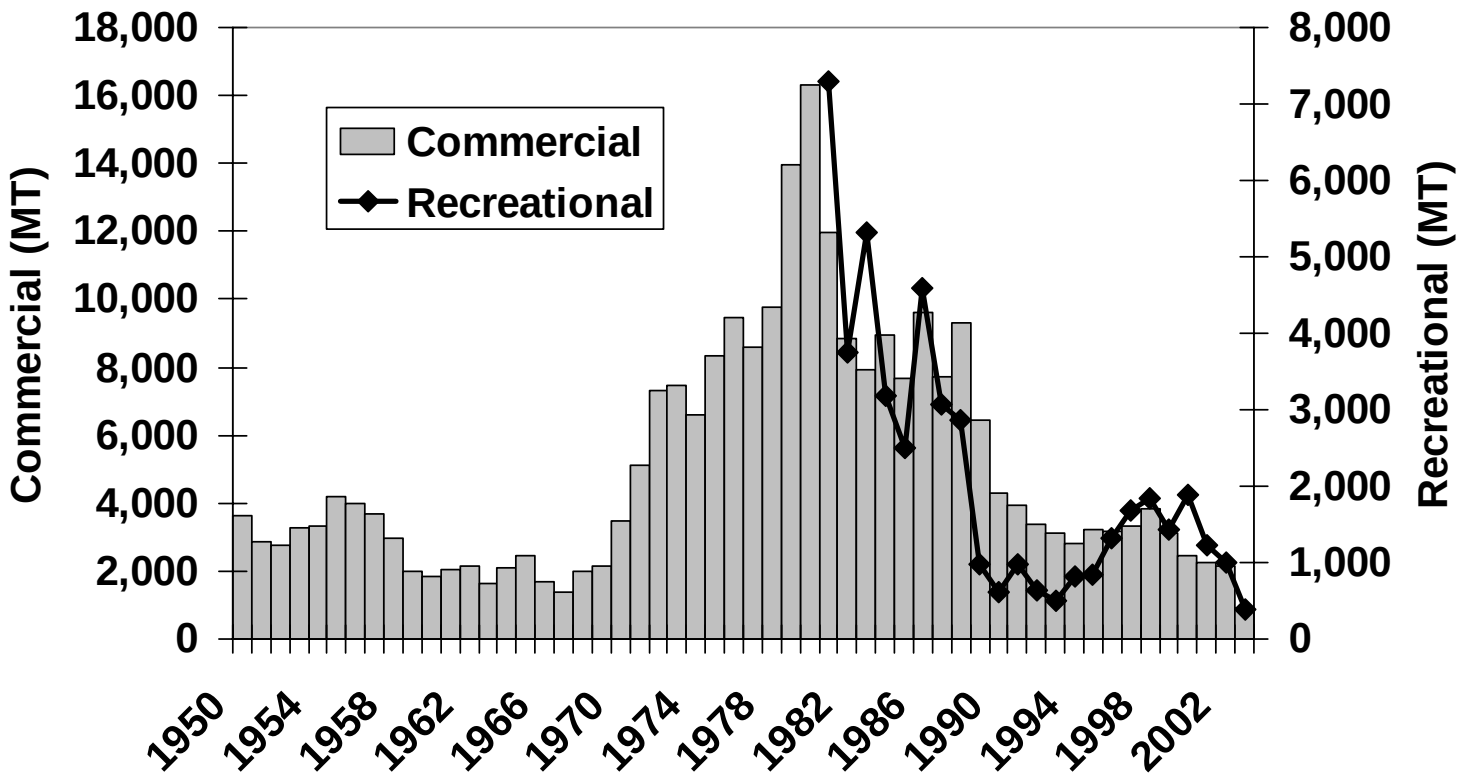


**Figure 2. WEAKFISH LANDINGS BY SECTOR, 1981-2004**

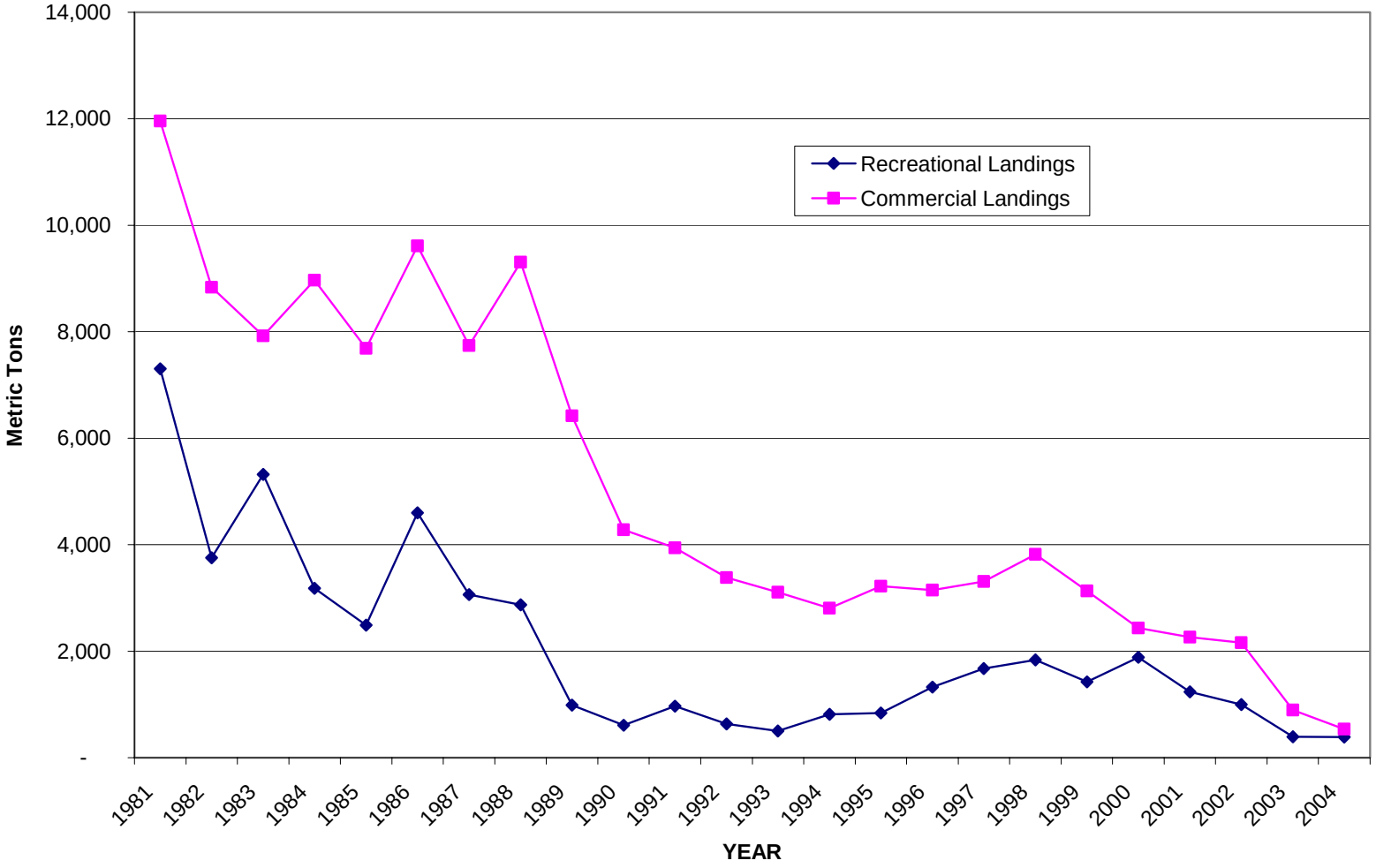


**Figure 2a. Coastwide Weakfish Recreational Catch and Harvest Through 2004**

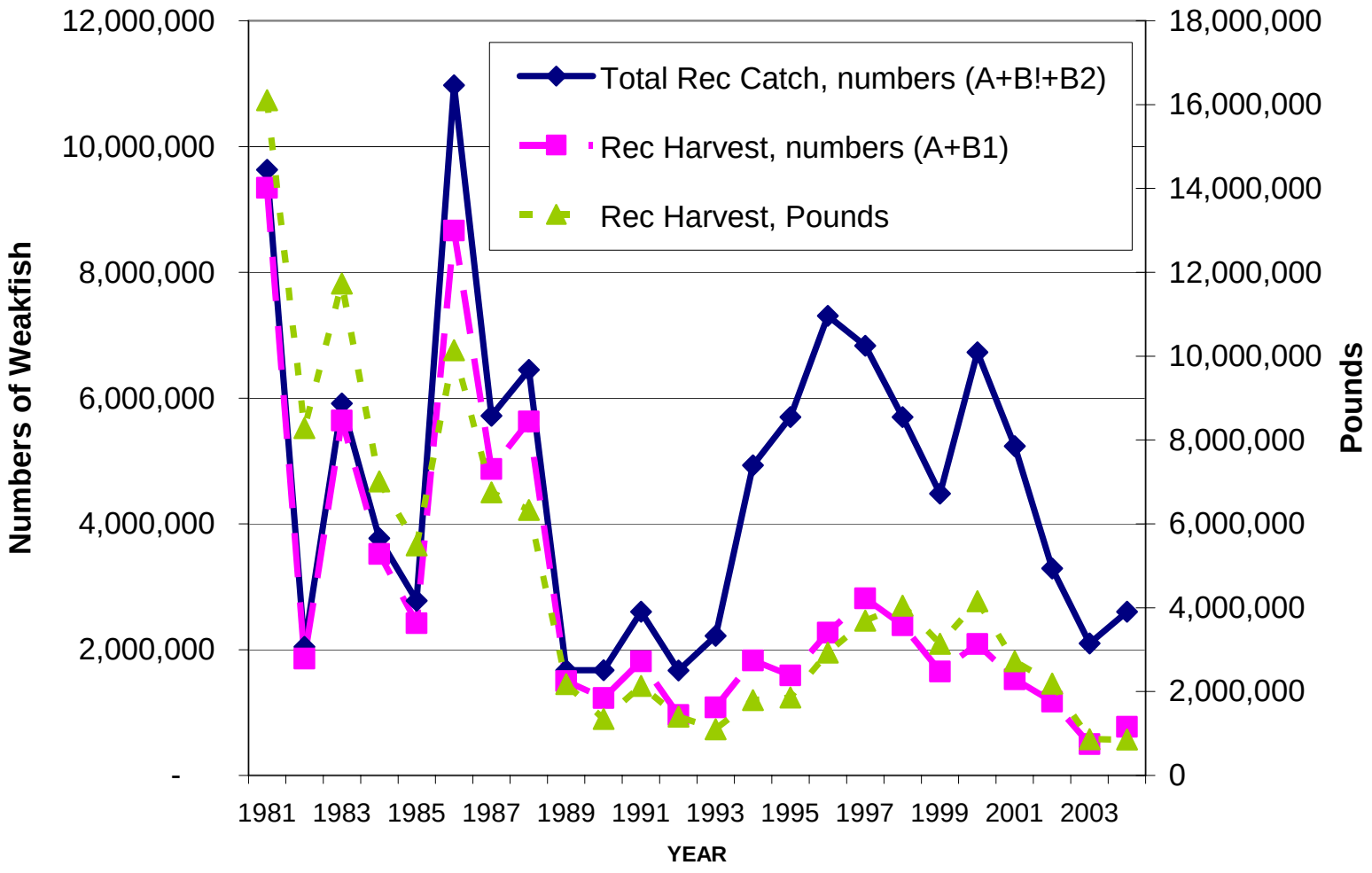
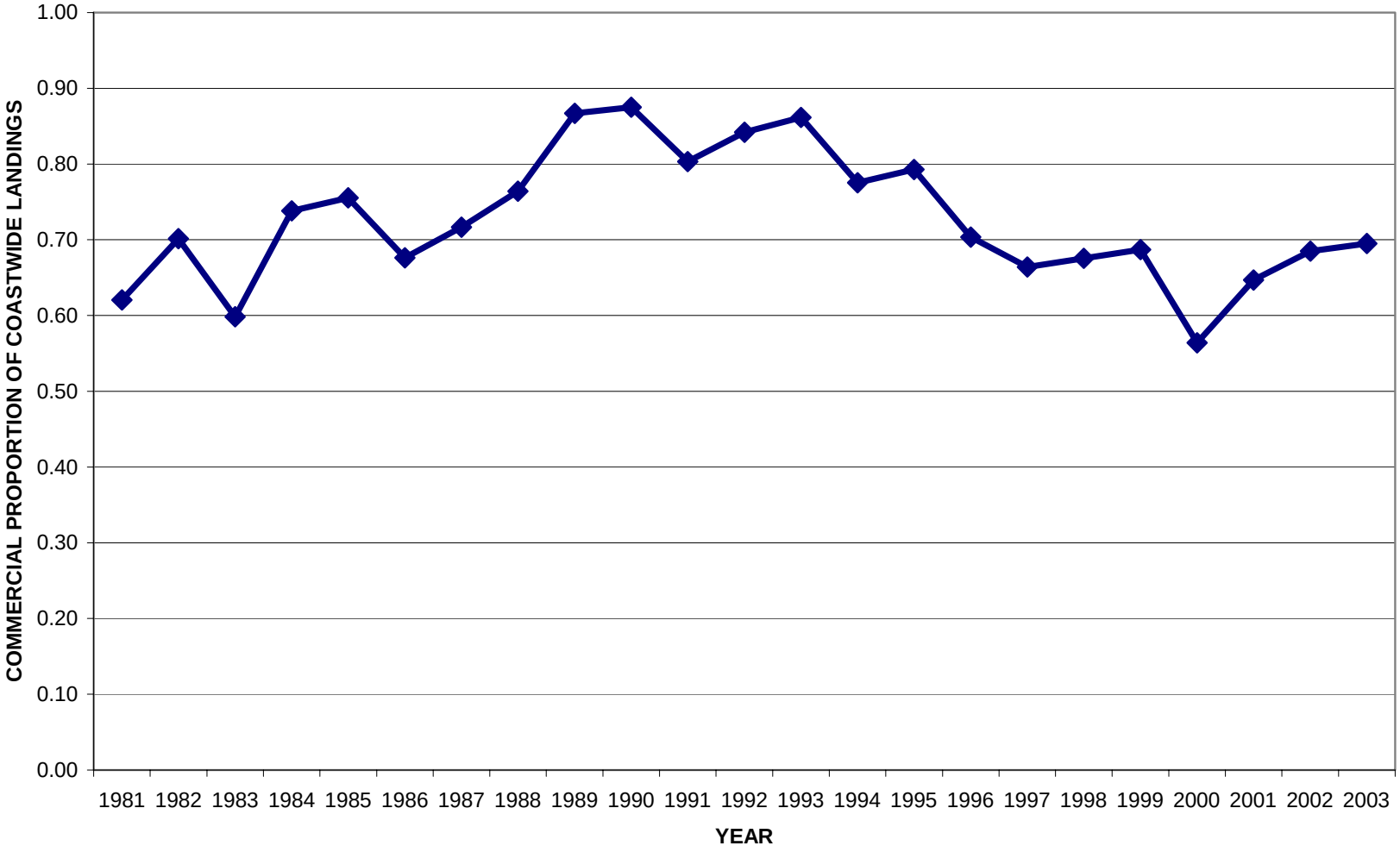


**Figure 3. Commercial proportion of Coastwide Landings**



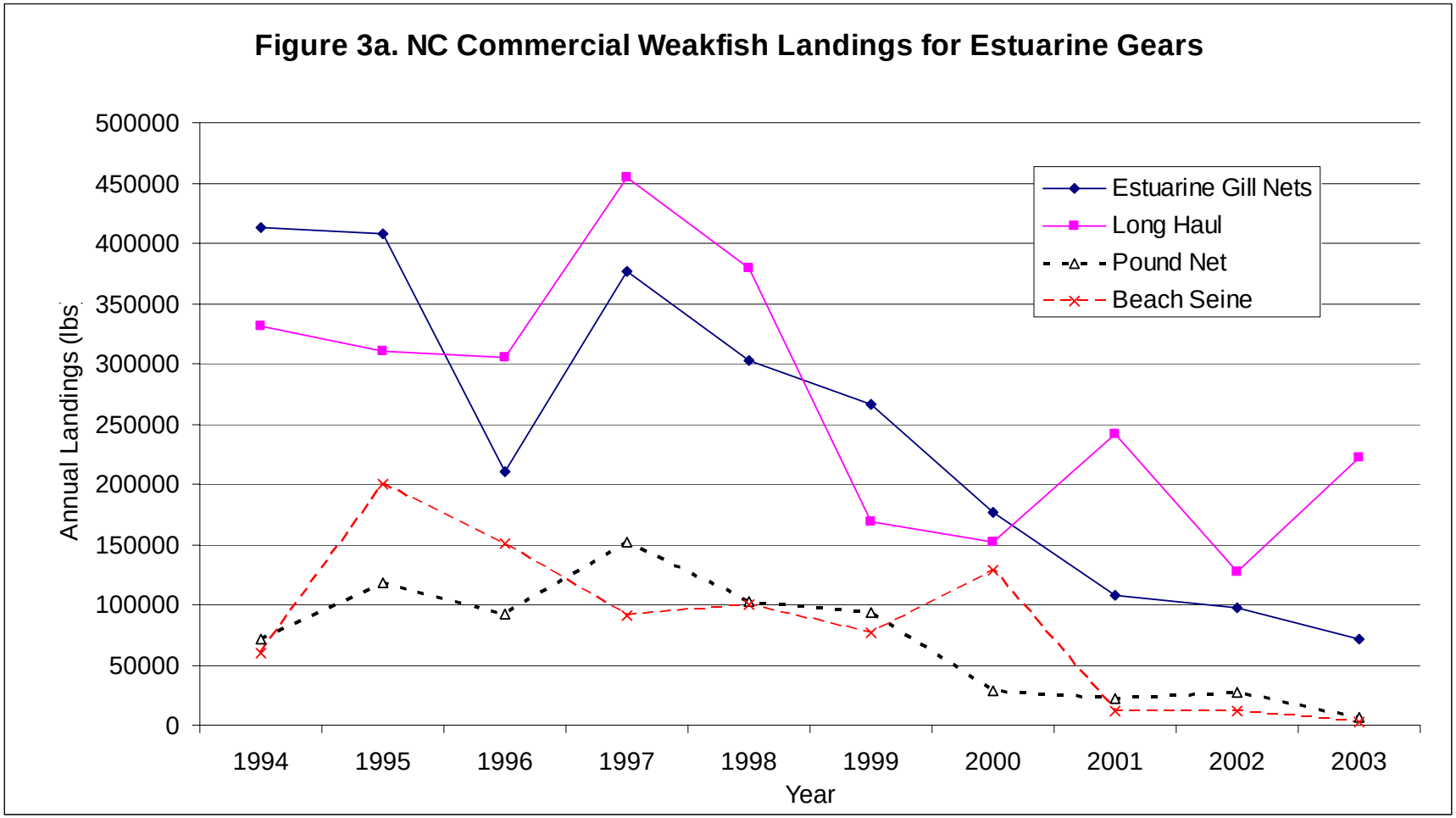


Figure 3a. NC Commercial Weakfish Landings for Estuarine Gears
Annual Landings (lbs)
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Year
Estuarine Gill Nets
Long Haul
Pound Net
Beach Seine

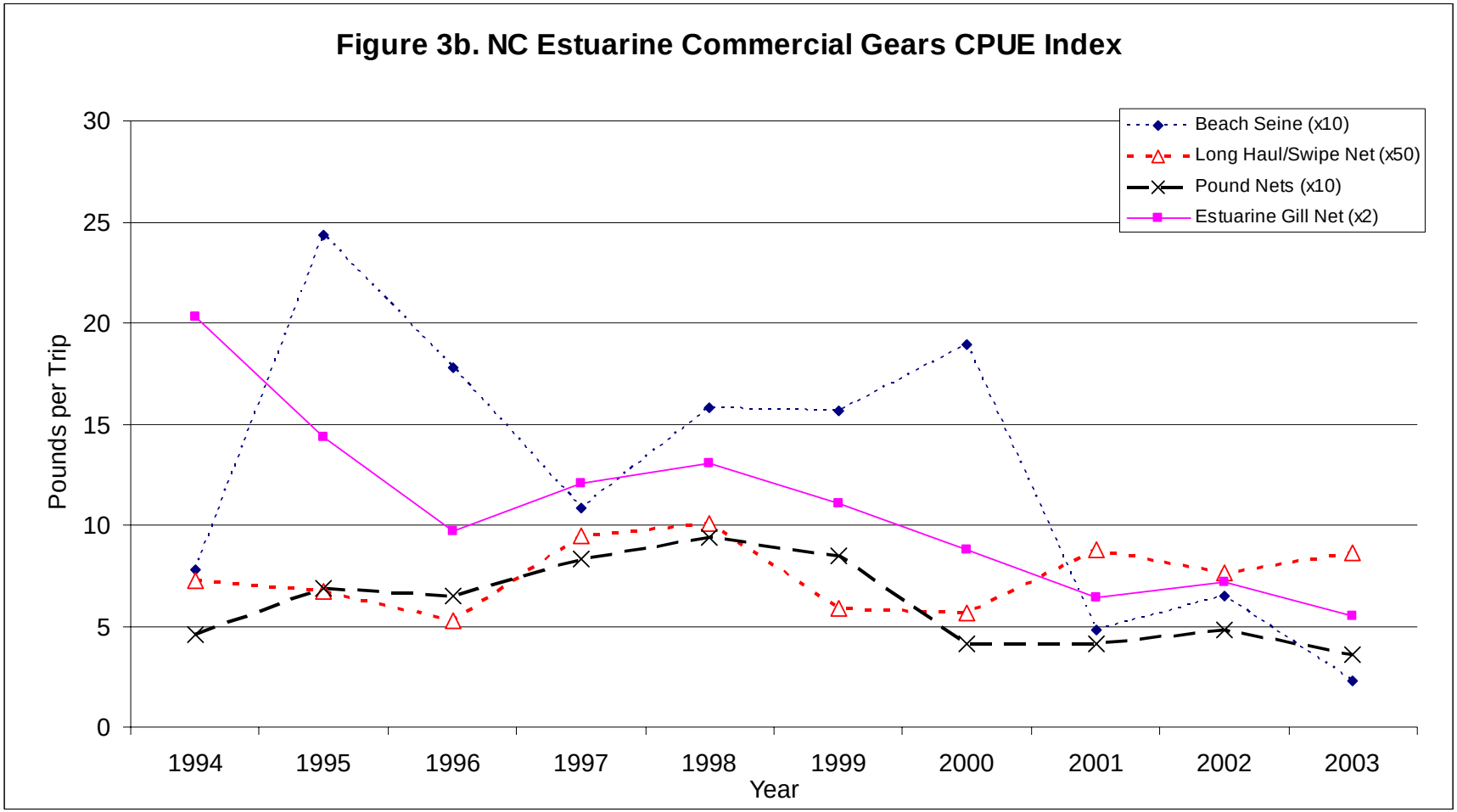


Figure 3b. NC Estuarine Commercial Gears CPUE Index
Beach Seine (x10)
Long Haul/Swipe Net (x50)
Pound Nets (x10)
Estuarine Gill Net (x2)
Pounds per Trip
30
25
20
15
10
5
0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Year

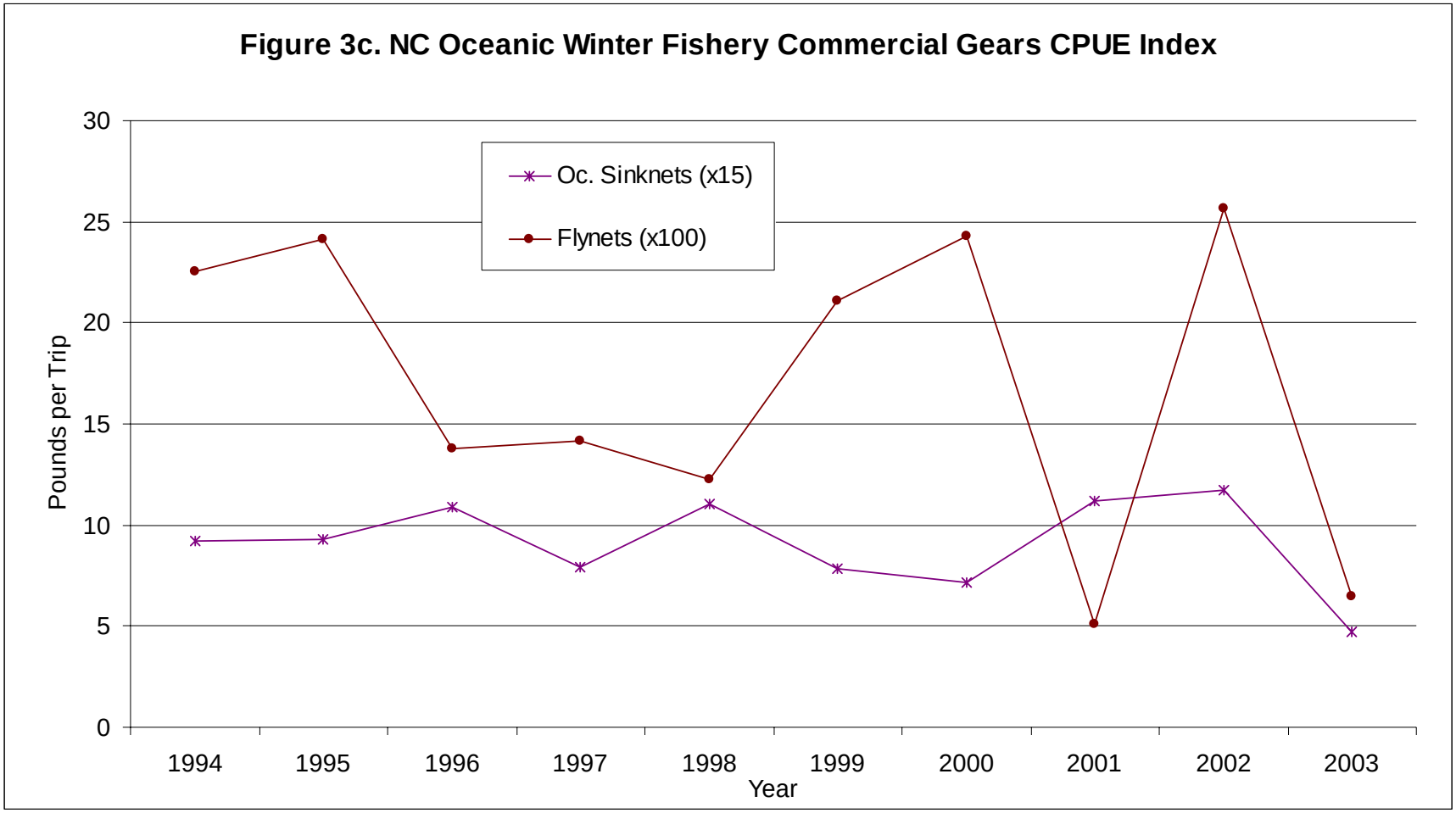


Figure 3c. NC Oceanic Winter Fishery Commercial Gears CPUE Index
Oc. Sinknets (x15)
Flynets (x100)
Pounds per Trip
30
25
20
15
10
5
0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Year

# Figure 3d. Recreational fishery Catch-per-trip Indices of Relative Abundance

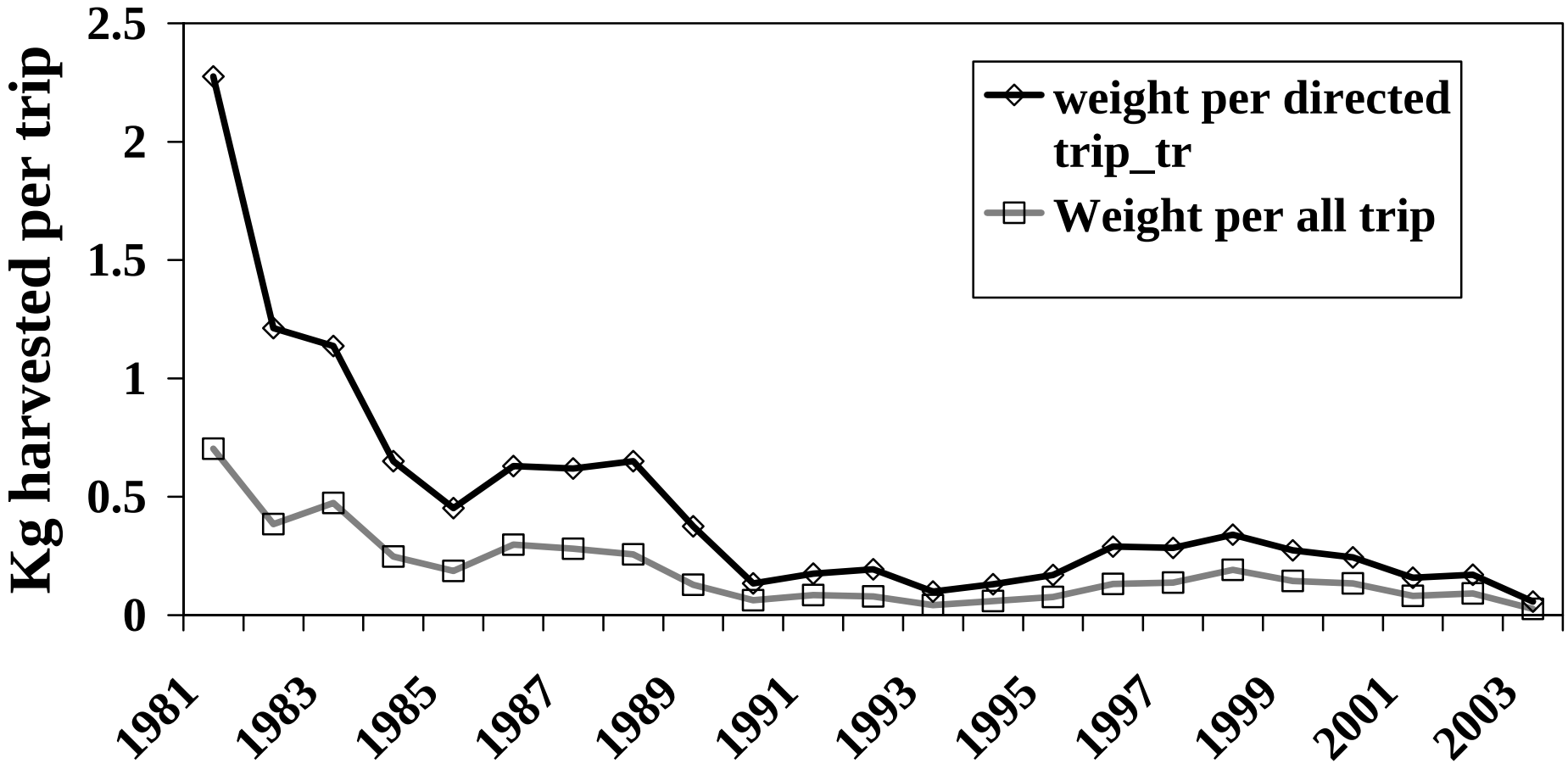


**Figure 3e. Recreational harvest per trip age-structured tuning indices and total catch per trip aggregated for ages 2-6**

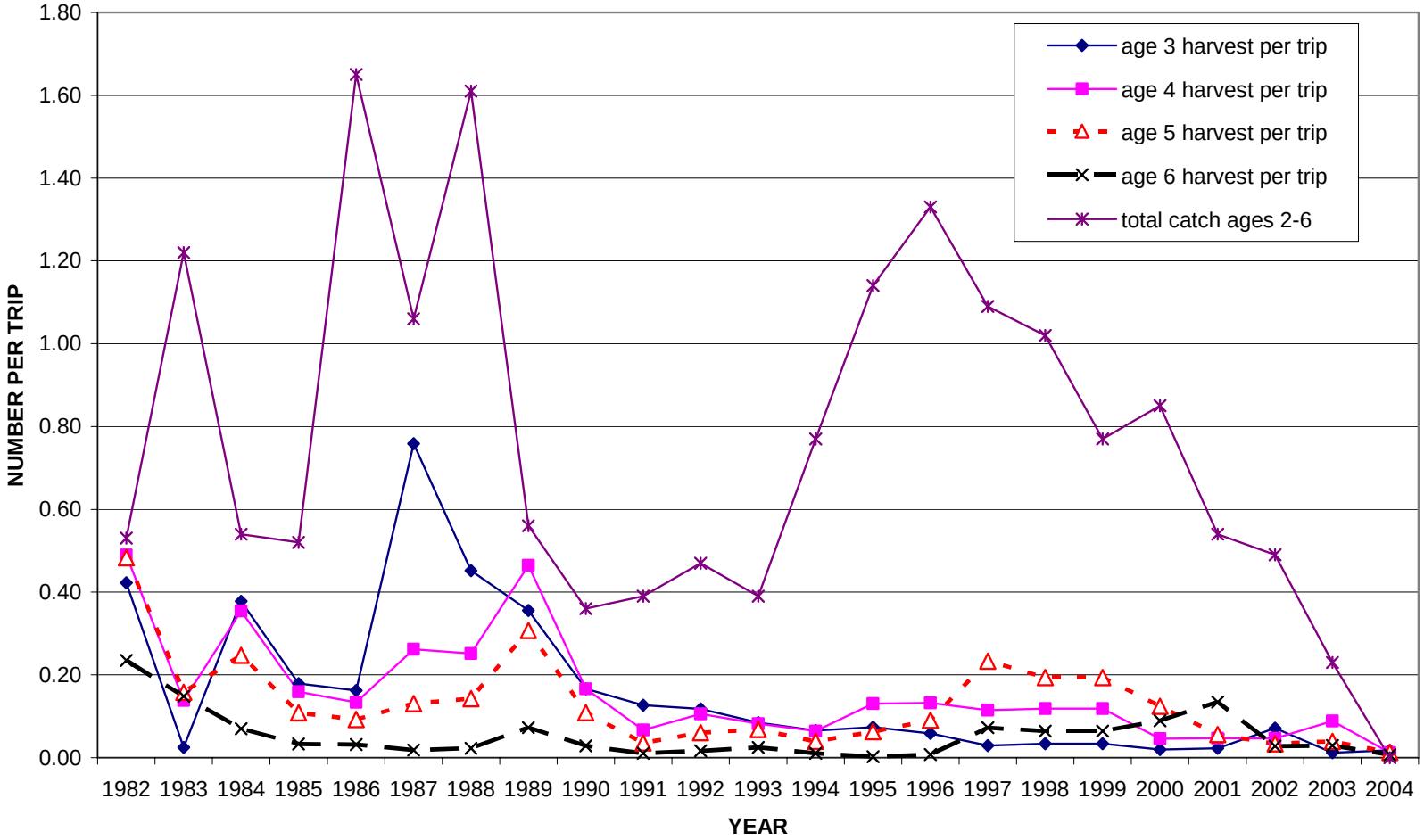


**Figure 3f. Relative Abundance from Mid-Atlantic Private Boat Total Catch and Total Trips**

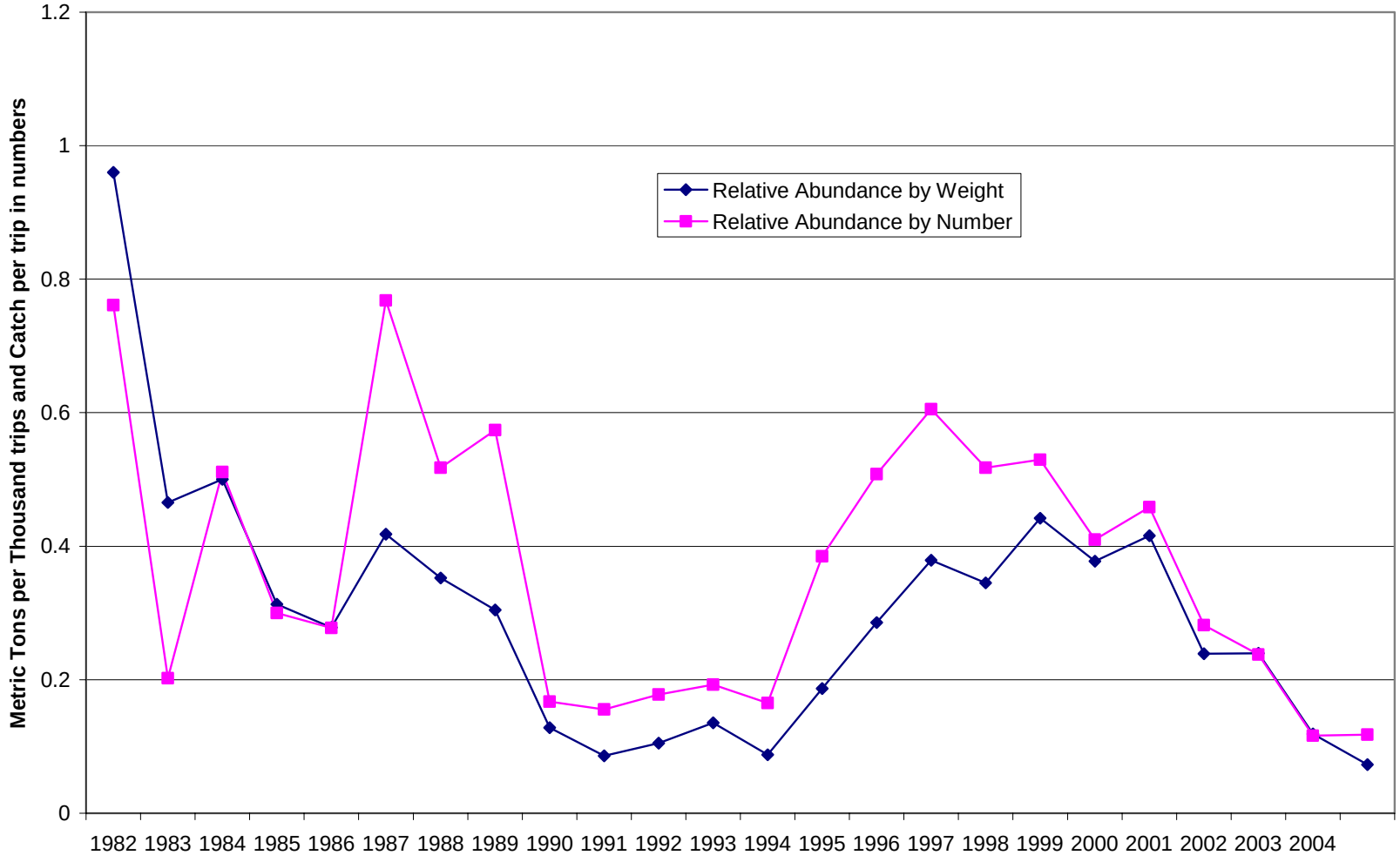


**FIGURE 4. NEFSC FALL INSHORE SURVEY TOTAL CATCH PER TOW**

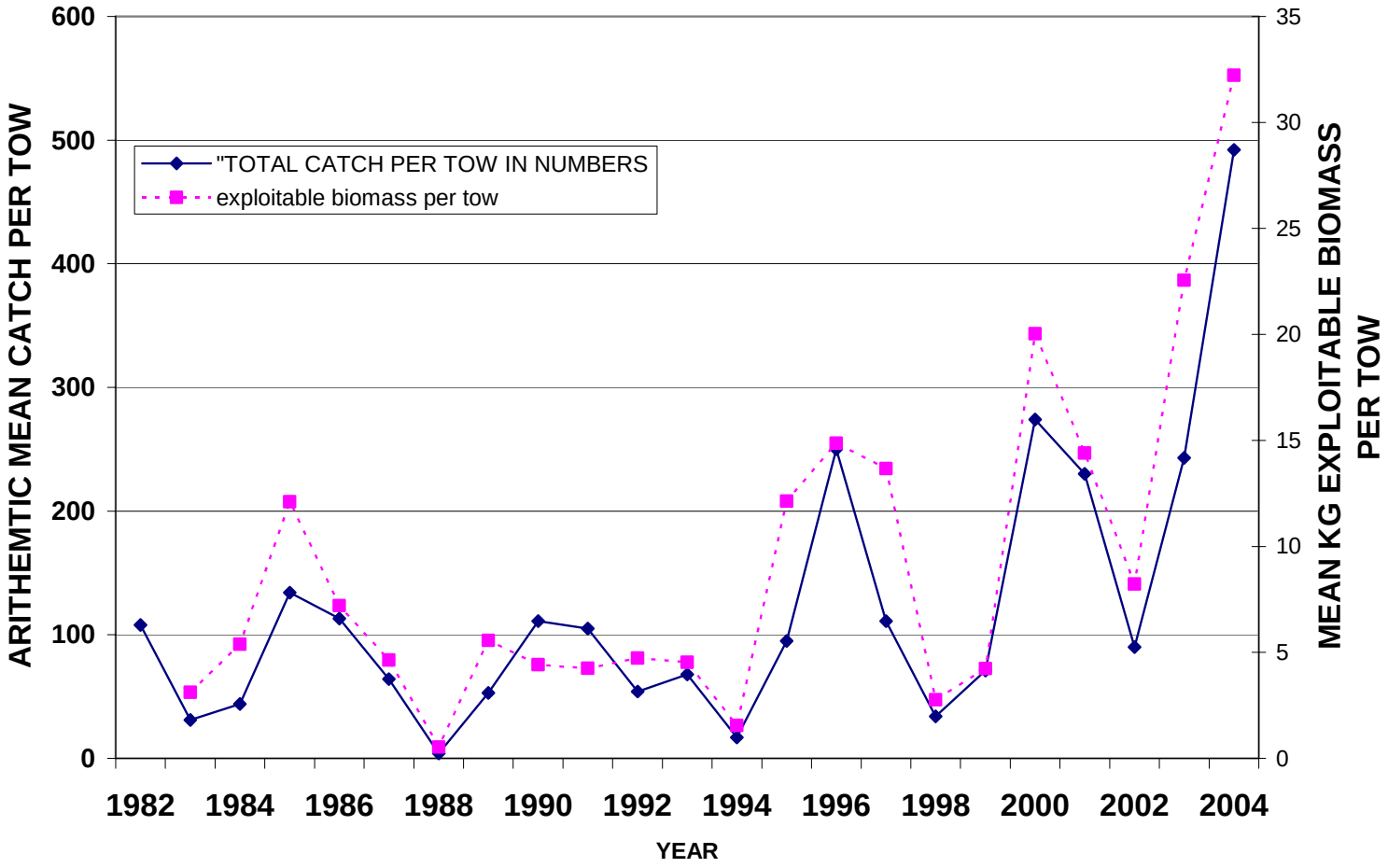


**FIGURE 5. NEFSC SURVEY INDICES BY AGE**

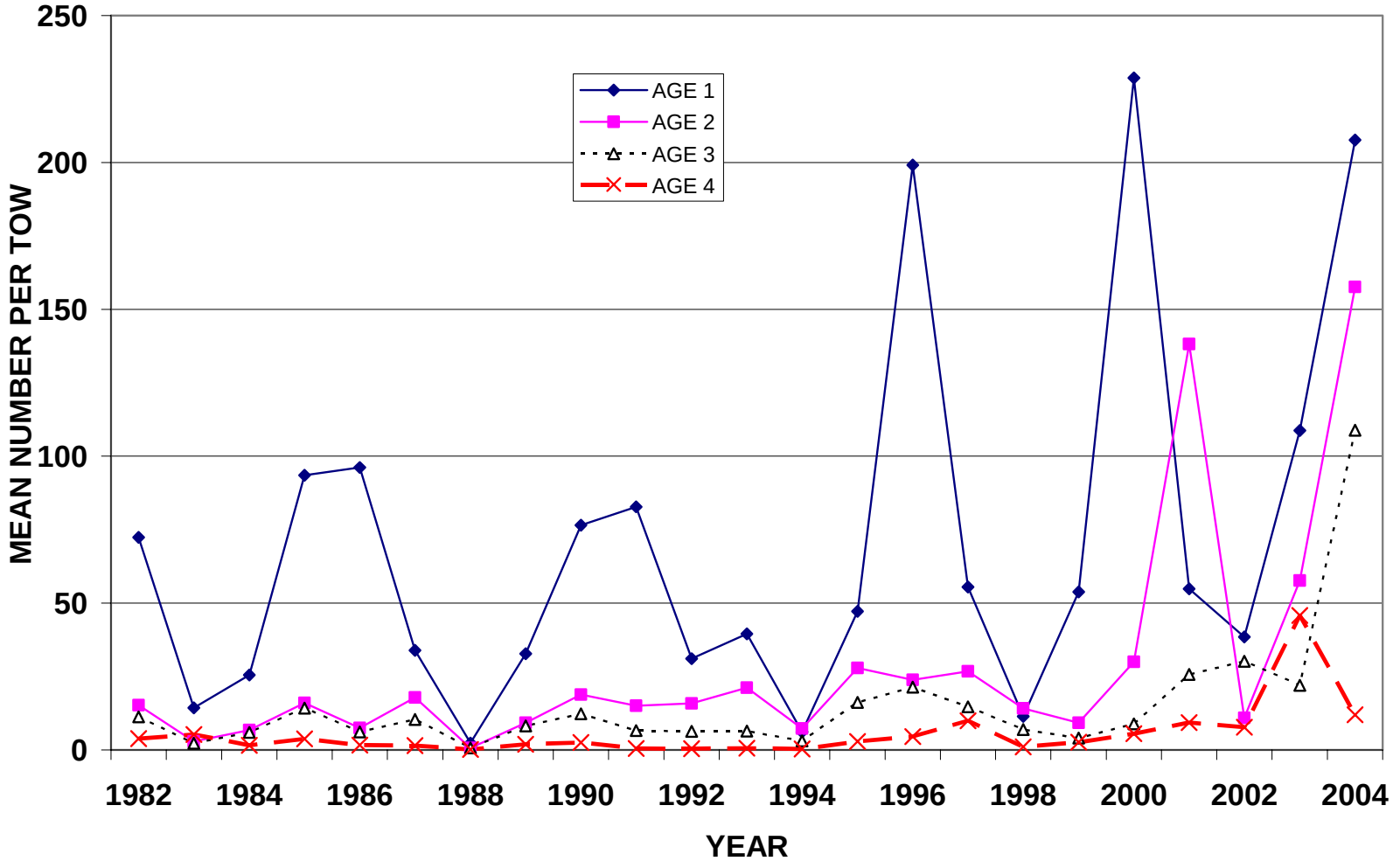


**Figure 6. NJ Survey Total Catch Per Tow**

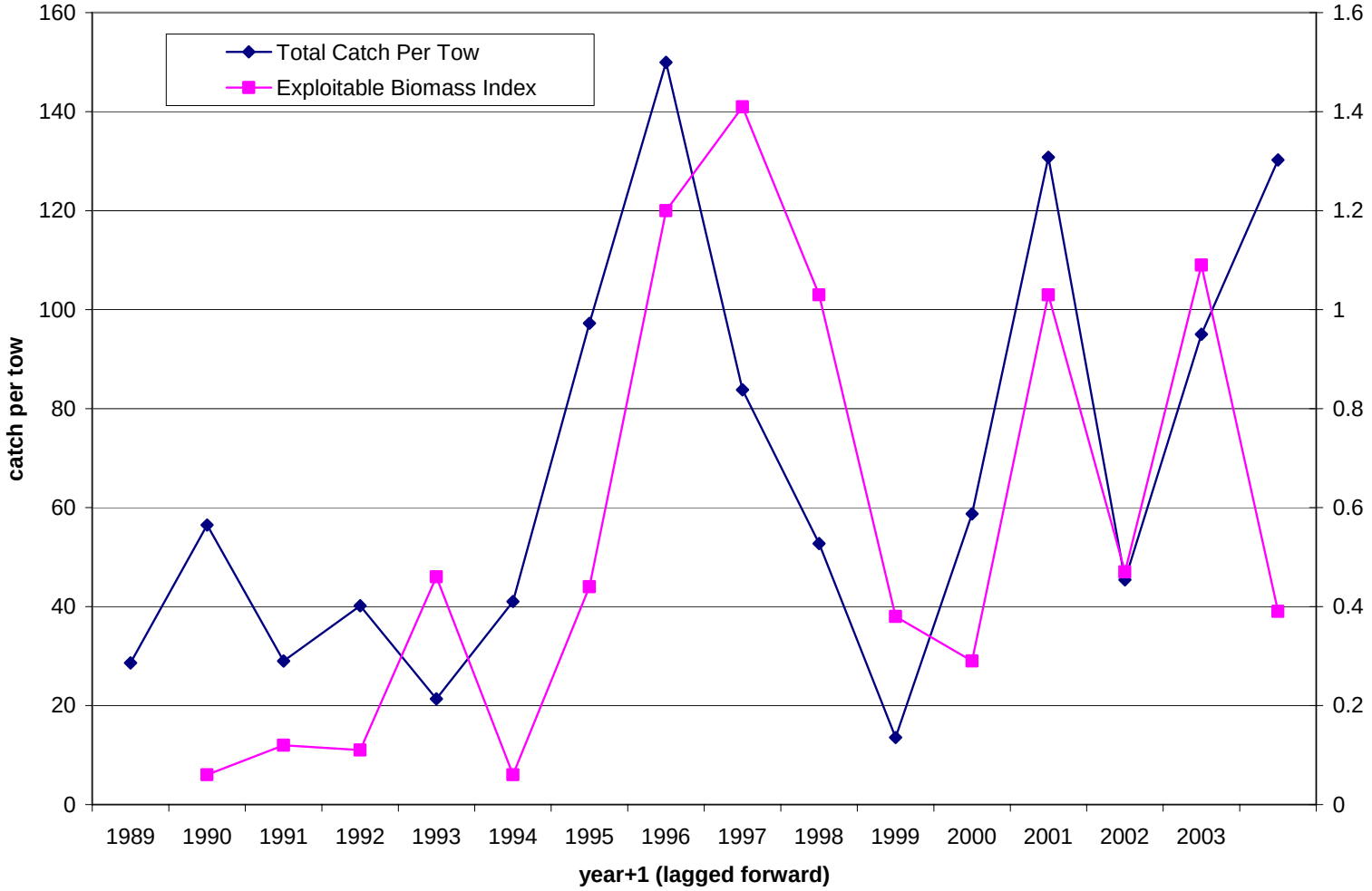


**FIGURE 7. NJ INDICES BY AGE**

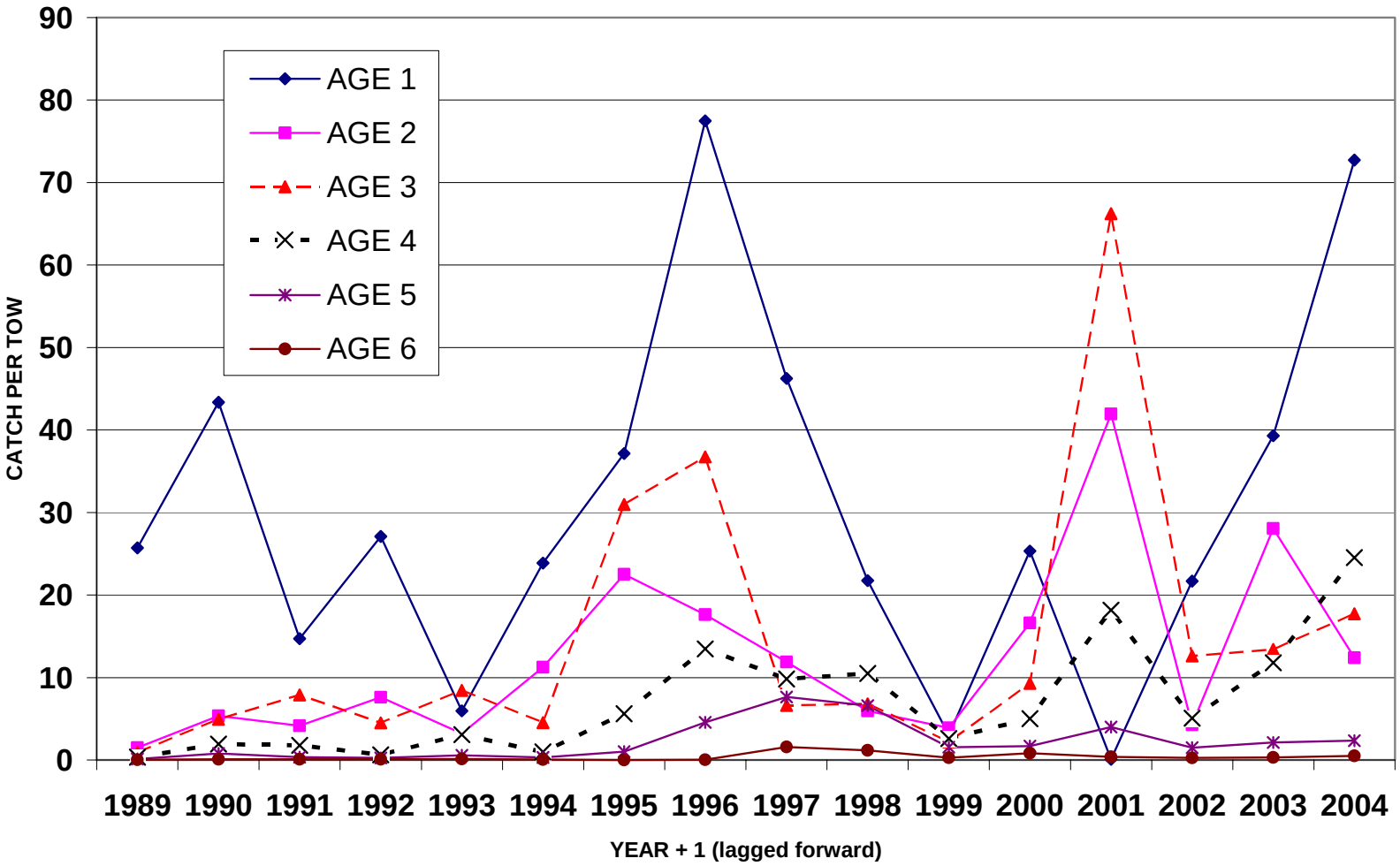


**FIGURE 8.DELAWARE SURVEY TOTAL CATCH PER TOW**

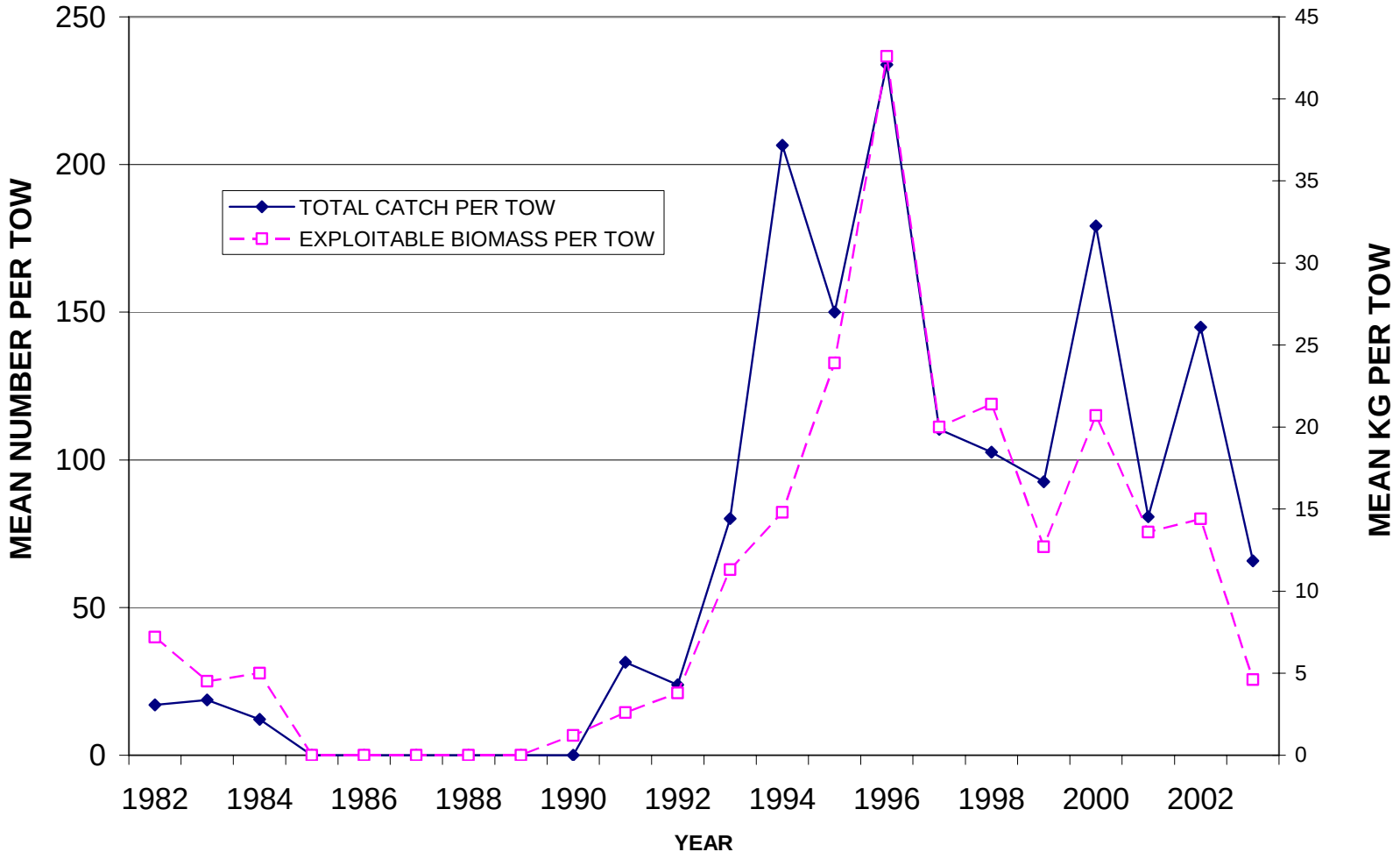


**FIGURE 9. DE SURVEY INDICES BY AGE**

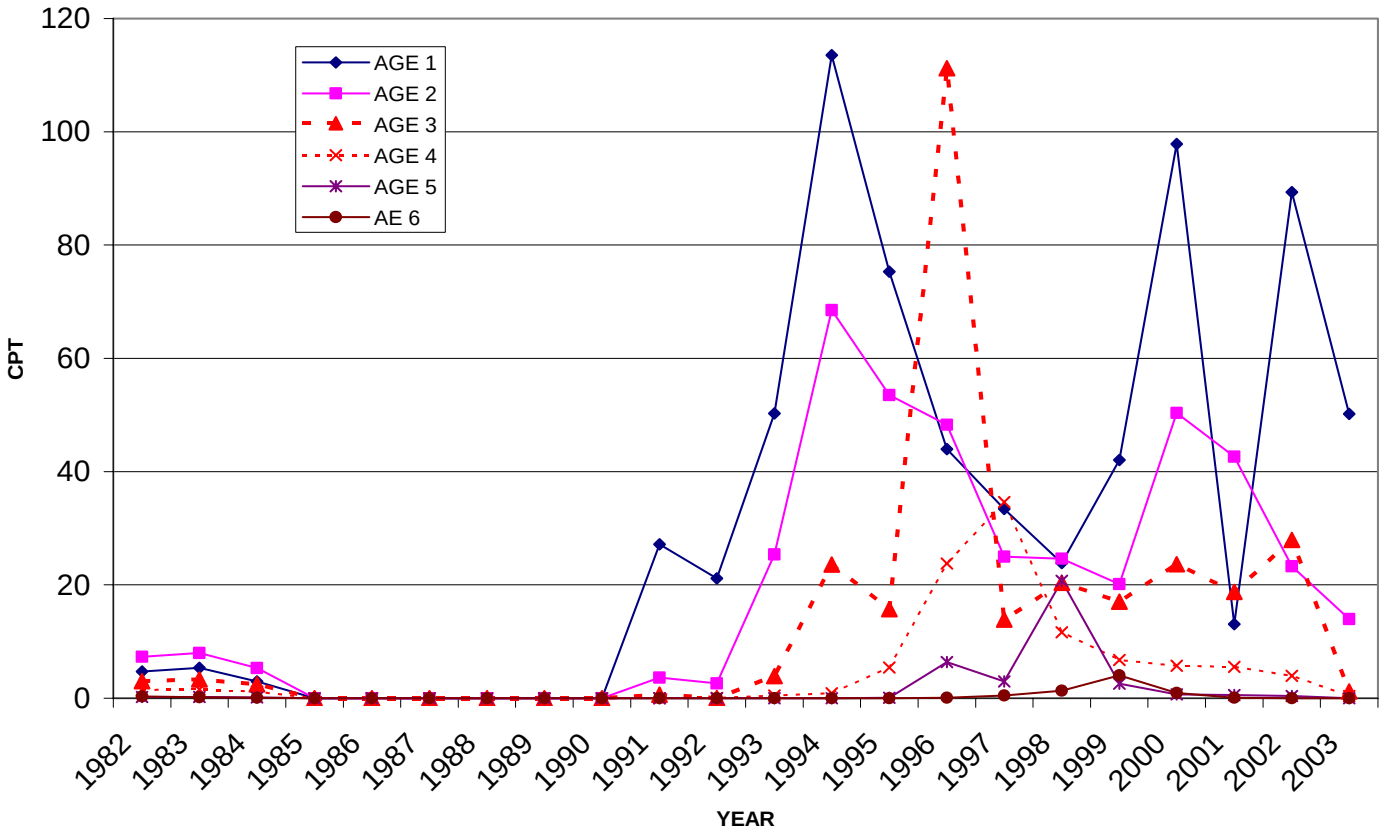


**Figure 9a. SEAMAP INDICES BY AGE**

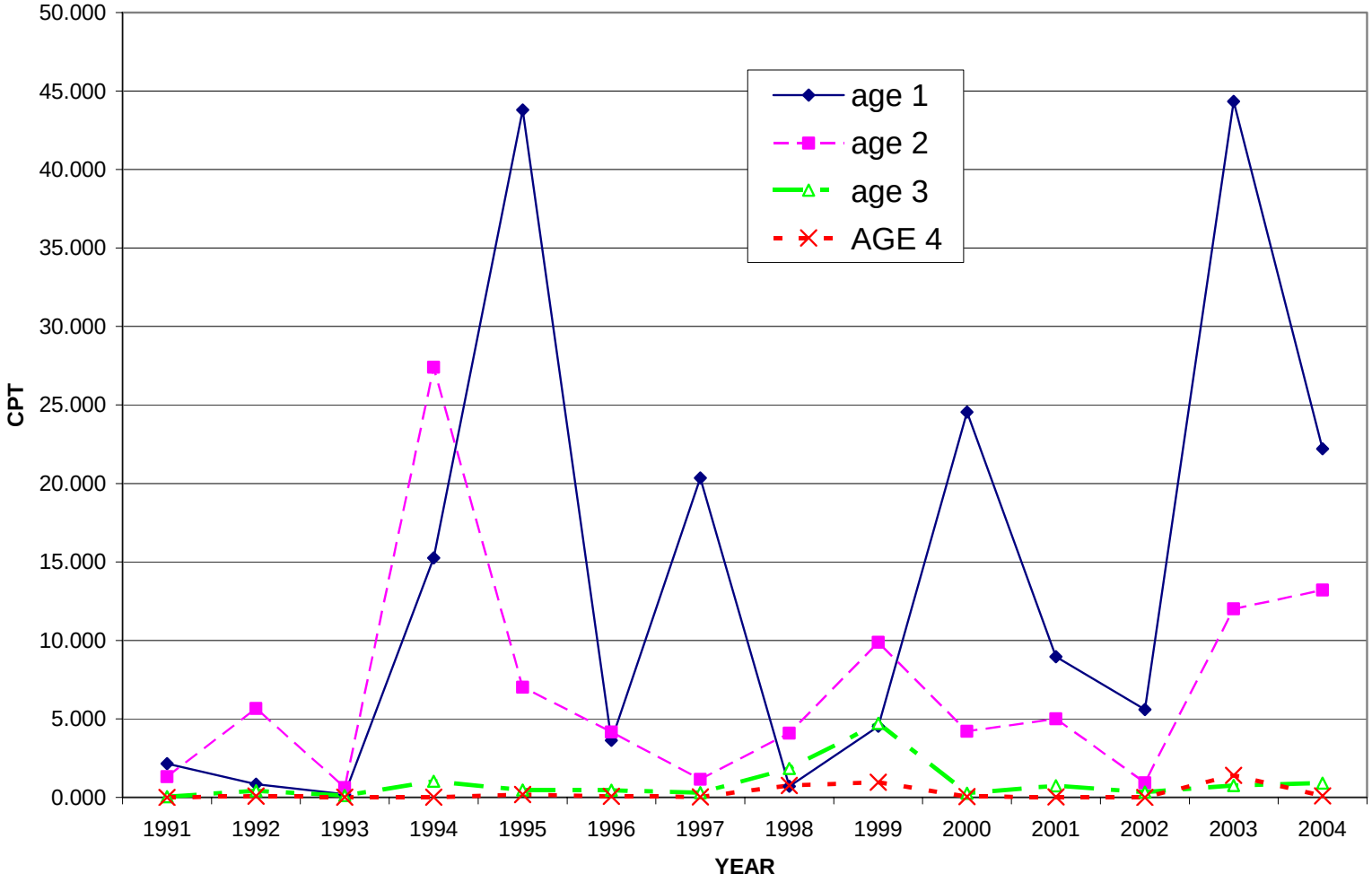


**Figure 9b. Relative F based on Recreational Total Catch in Weight and in Number**

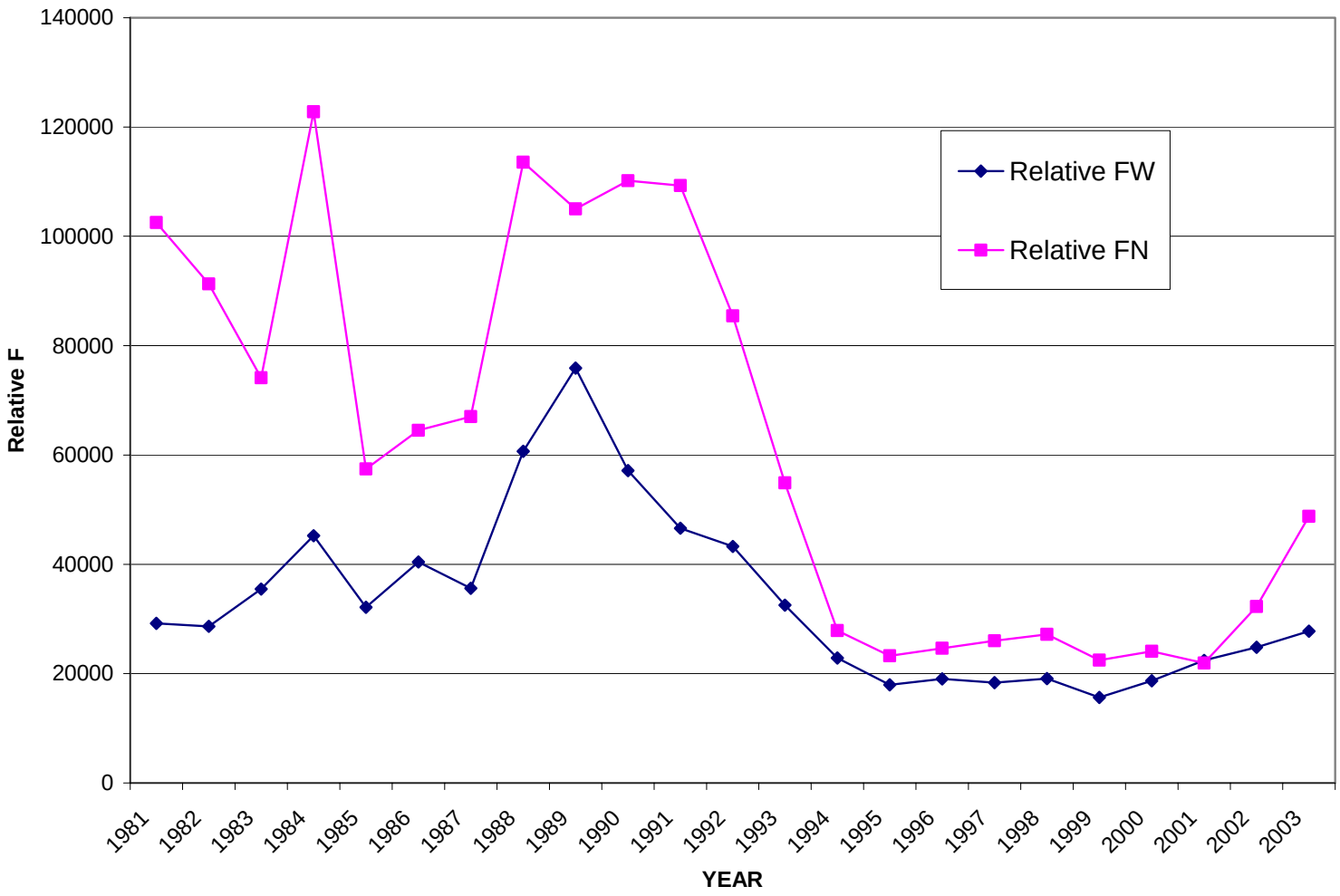


**Figure 9c. Relative F derived from Z + 1 transformed trawl survey exploitable biomass indices, divided by 10,000 to rescale.**

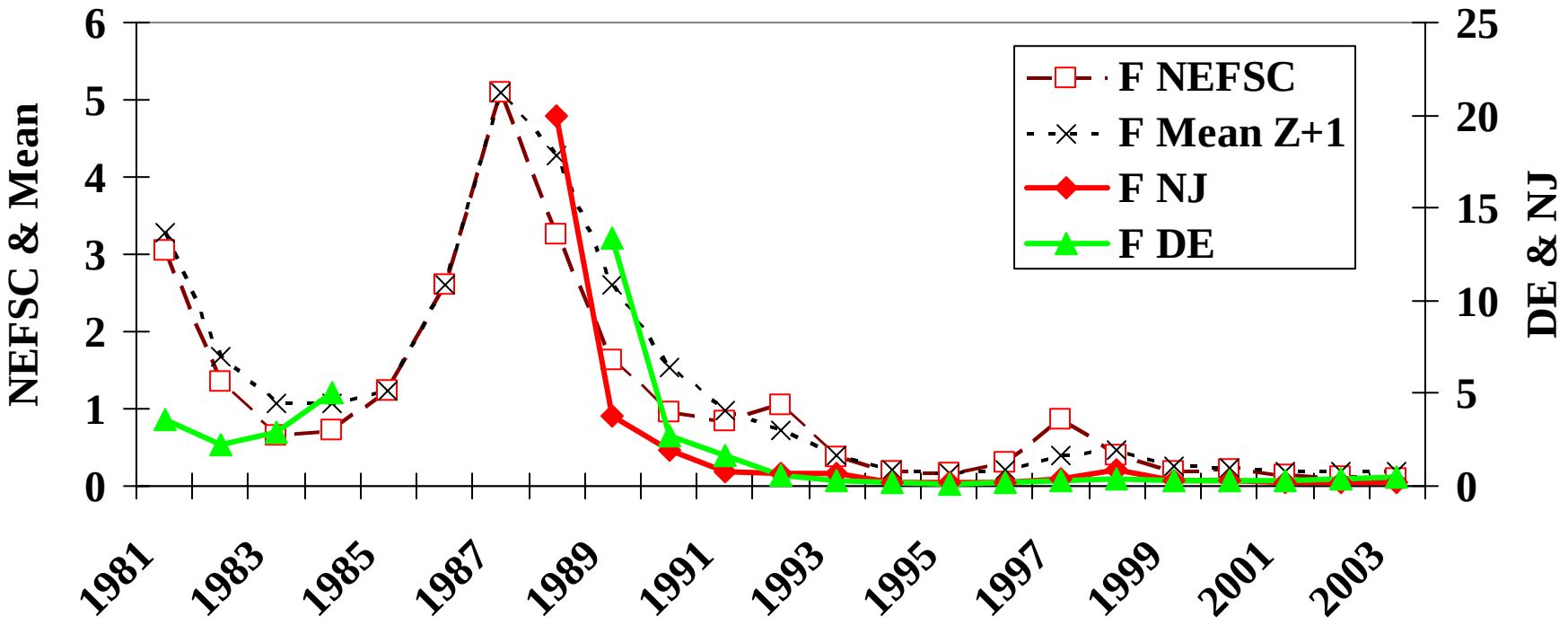


**Figure 10.EFFECT OF INCLUDING CORE SPECIES COMMERCIAL DISCARDS ON 2002 CAA**

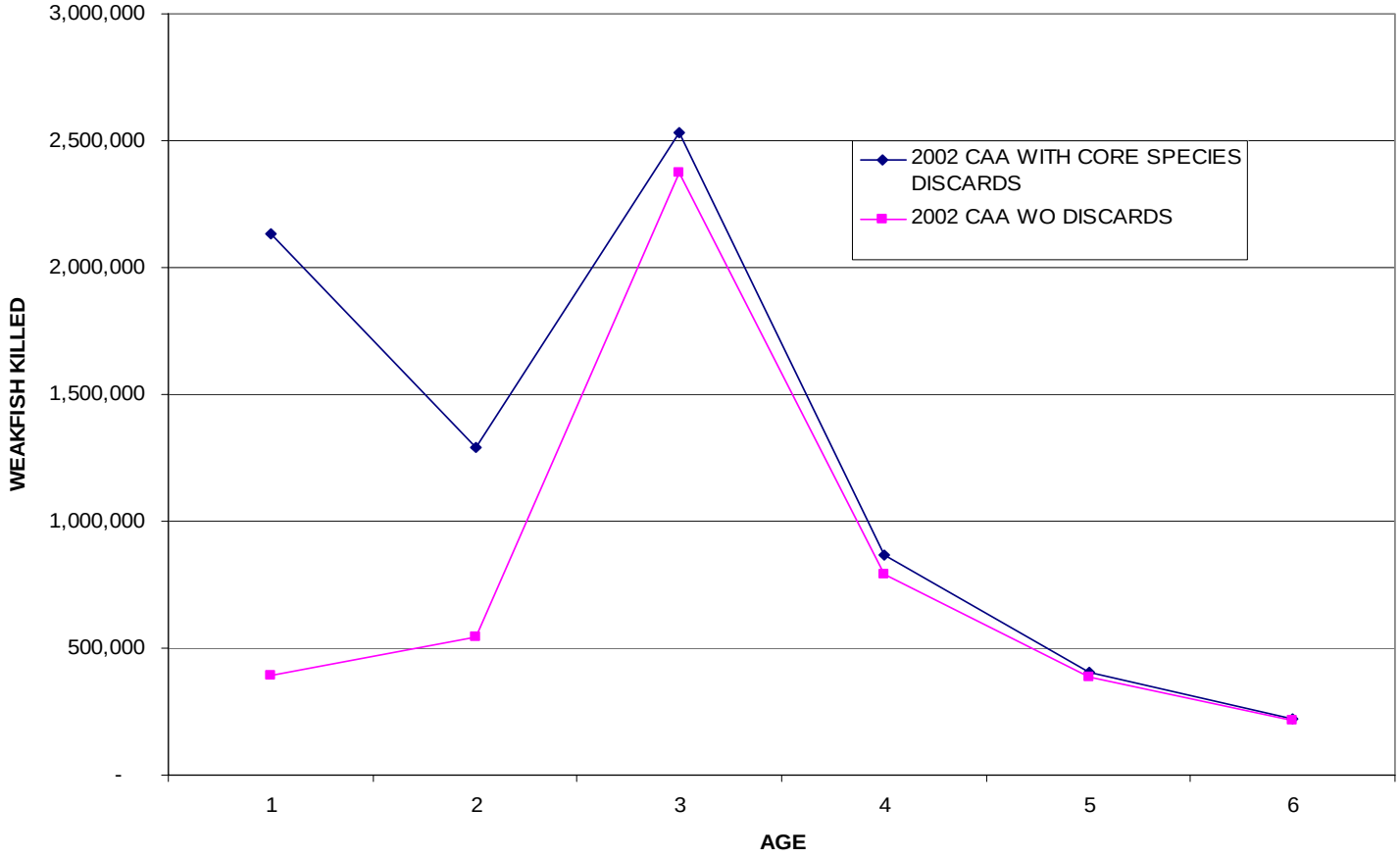


**Figure 11. Mean Weight at Age of the Commercial Harvest by State, 2001**

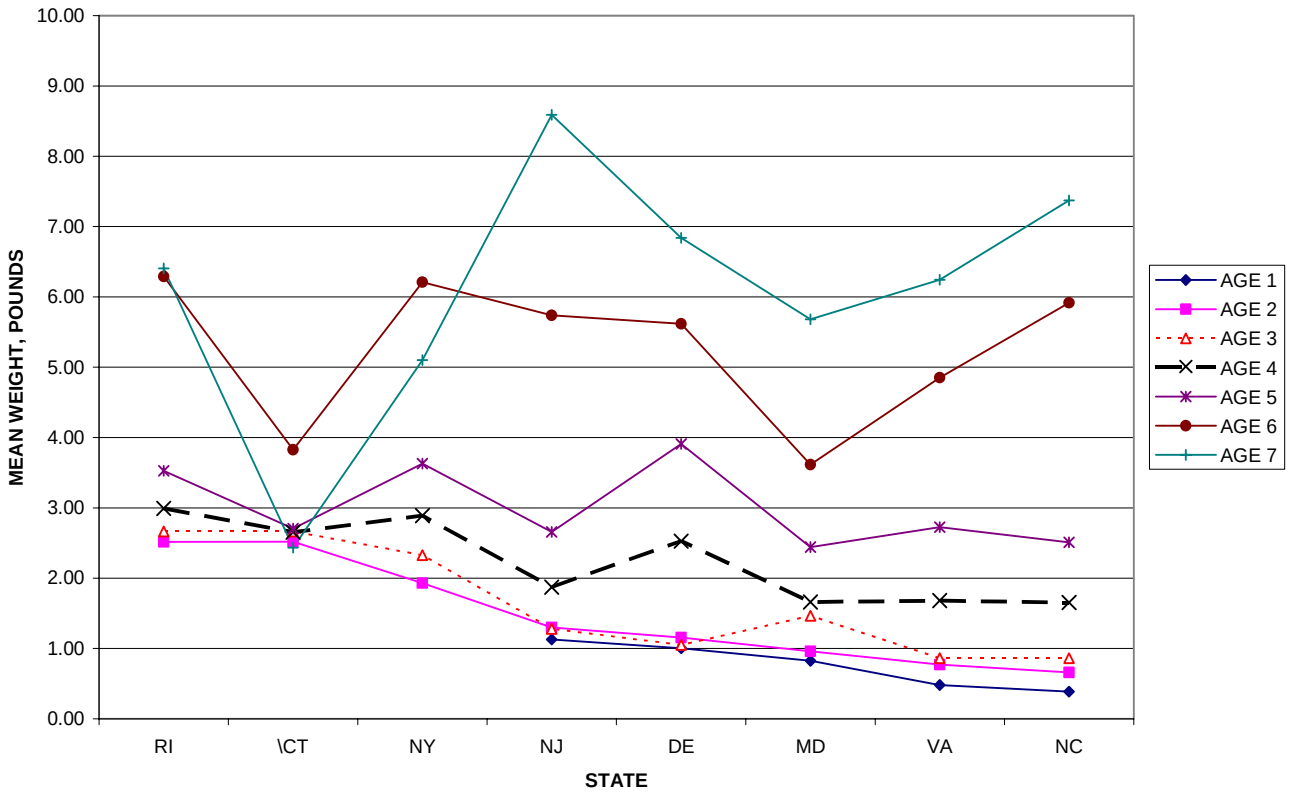


**Figure 12. Mean Weight at Age of the Commercial Harvest by State, 2002**

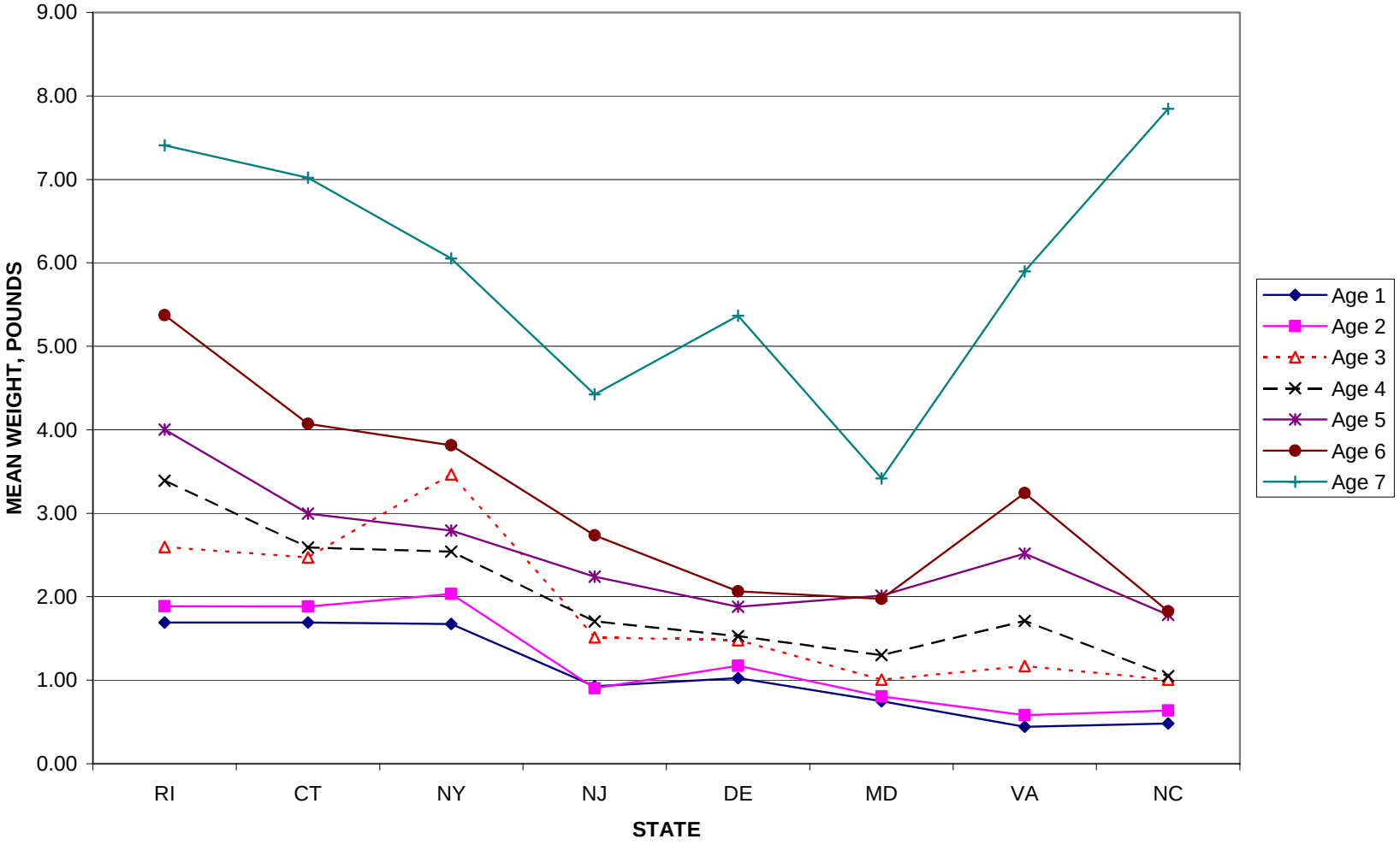


**Figure 13. Mean Weight at age of the commercial harvest by state, 2003**

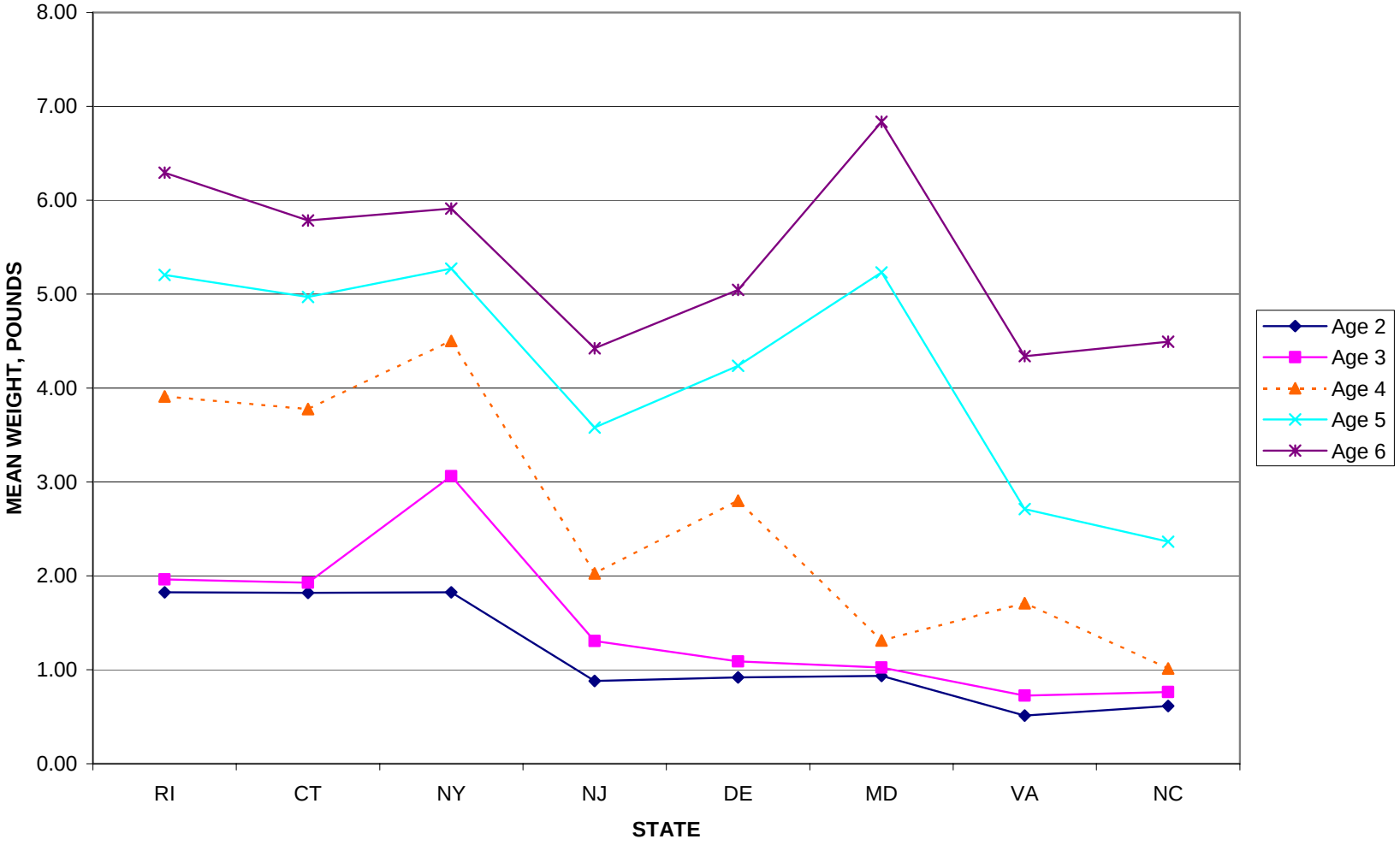


**Figure 14. January 1 Stock Mean Weight at Age**

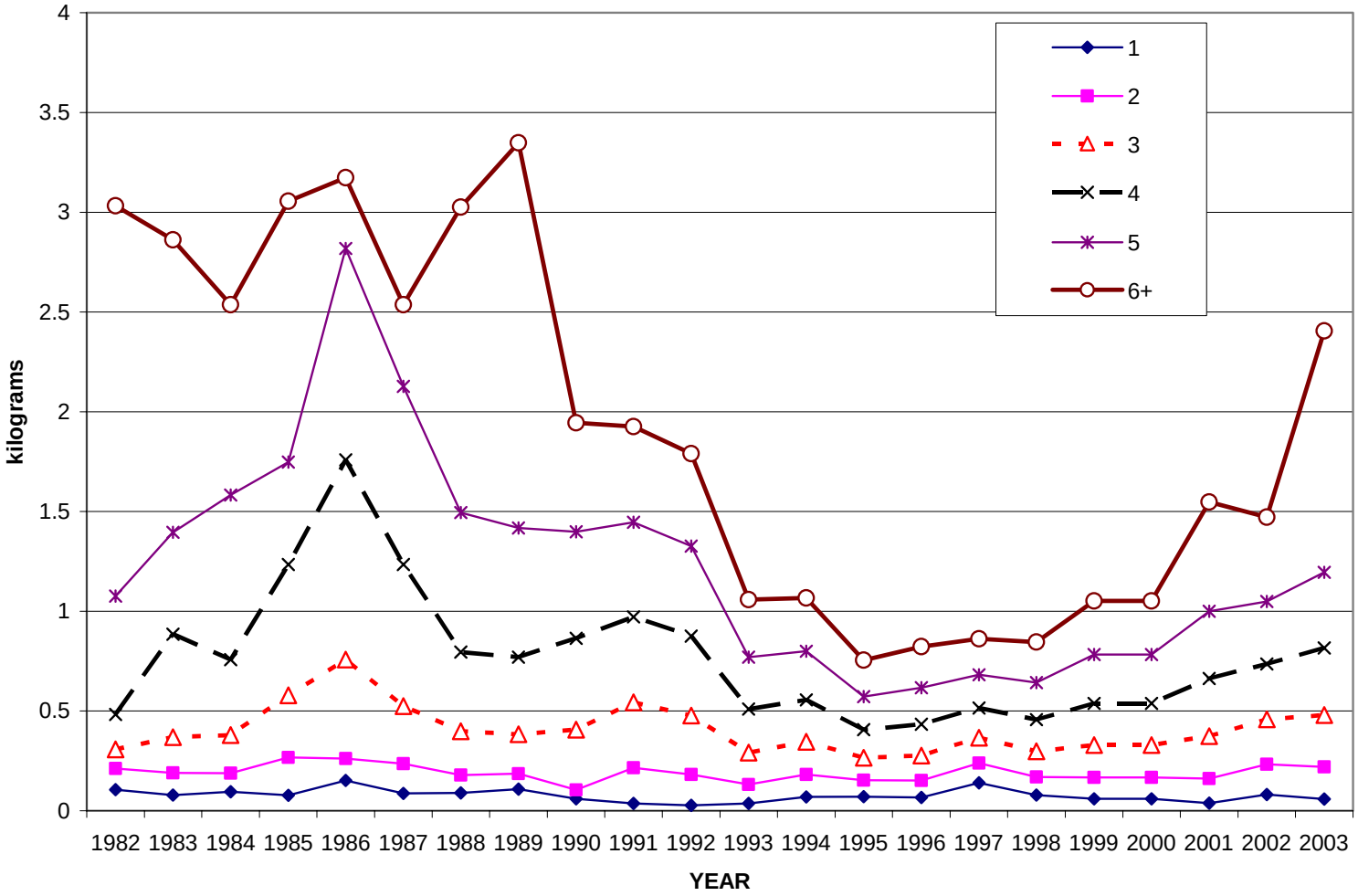


**Figure 15 Landings versus Sum of cross-products (mean catch weight-at-age * catch-at a-age)**

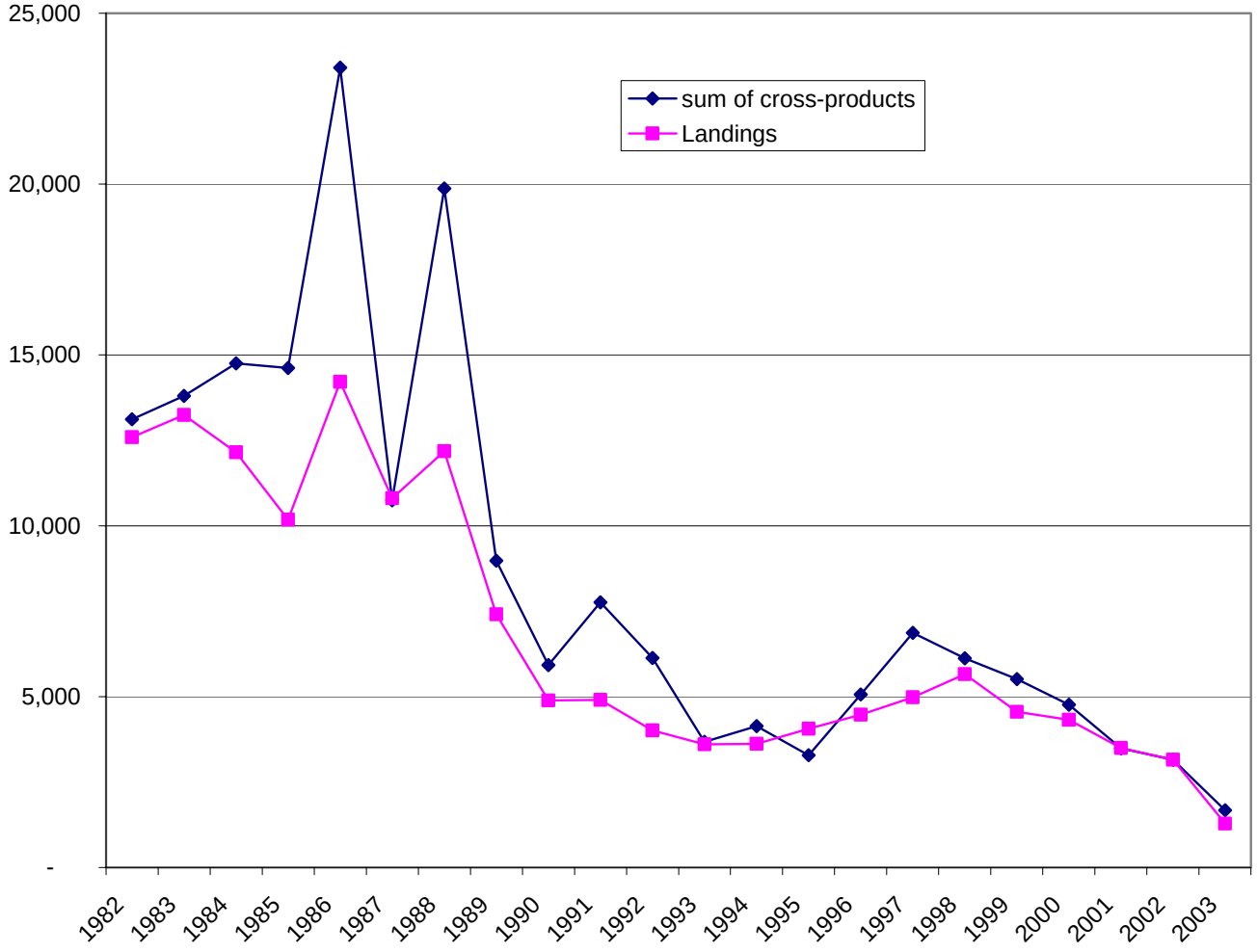


**Figure 16. Weakfish Mortality Estimated From Catch Curve Analysis of the Catch at Age Matrix**

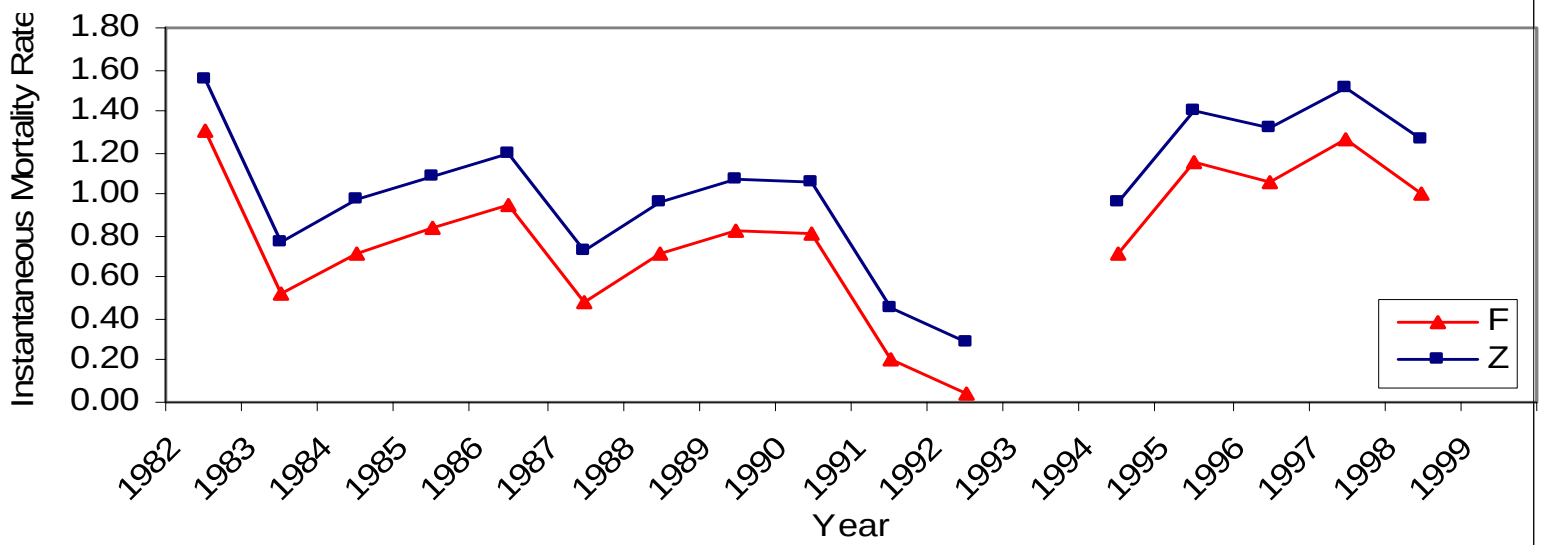


**FIGURE 17. CORRELATION BETWEEN YEAR CLASS Z ESTIMATES FROM CATCH CURVE ANALYSIS OF THE CATCH AT AGE MATRIX AND THE DELAWARE SURVEYFOR THE 1990 - 1998 YEAR CLASSES (1993 YEAR CLASS EXCLUDED)**

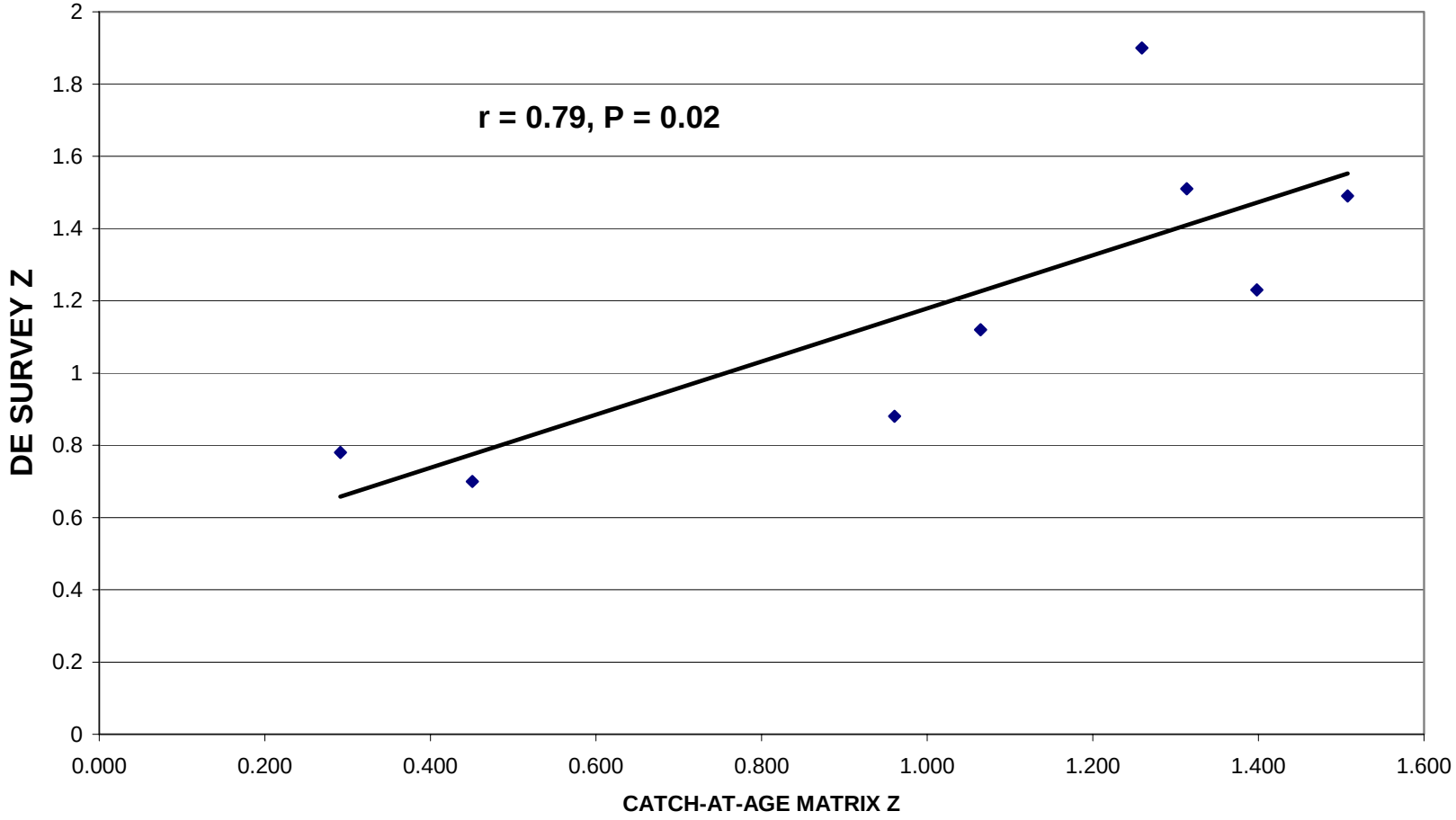
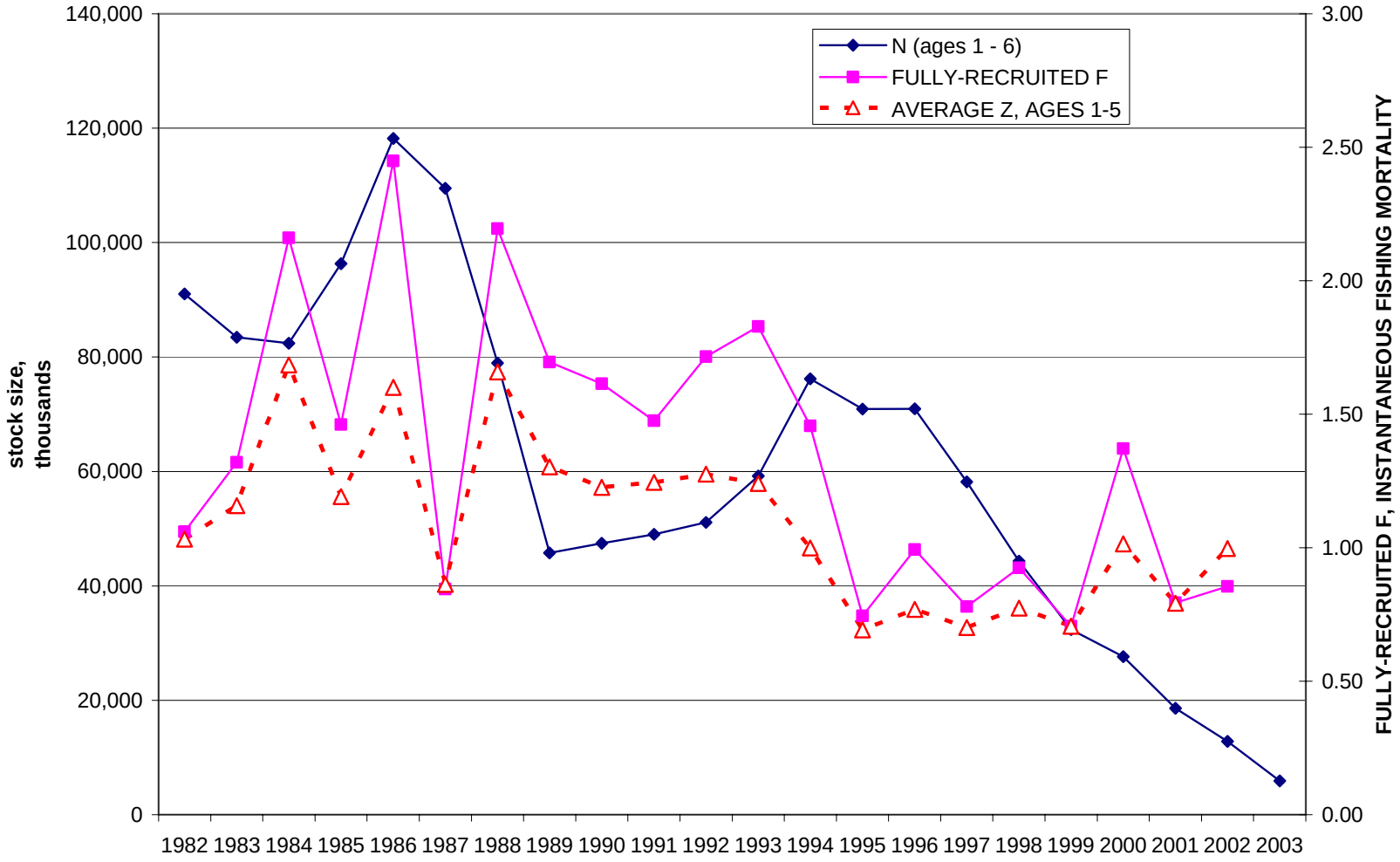


**Figure 18. Gulland's Cohort analysis for weakfish**



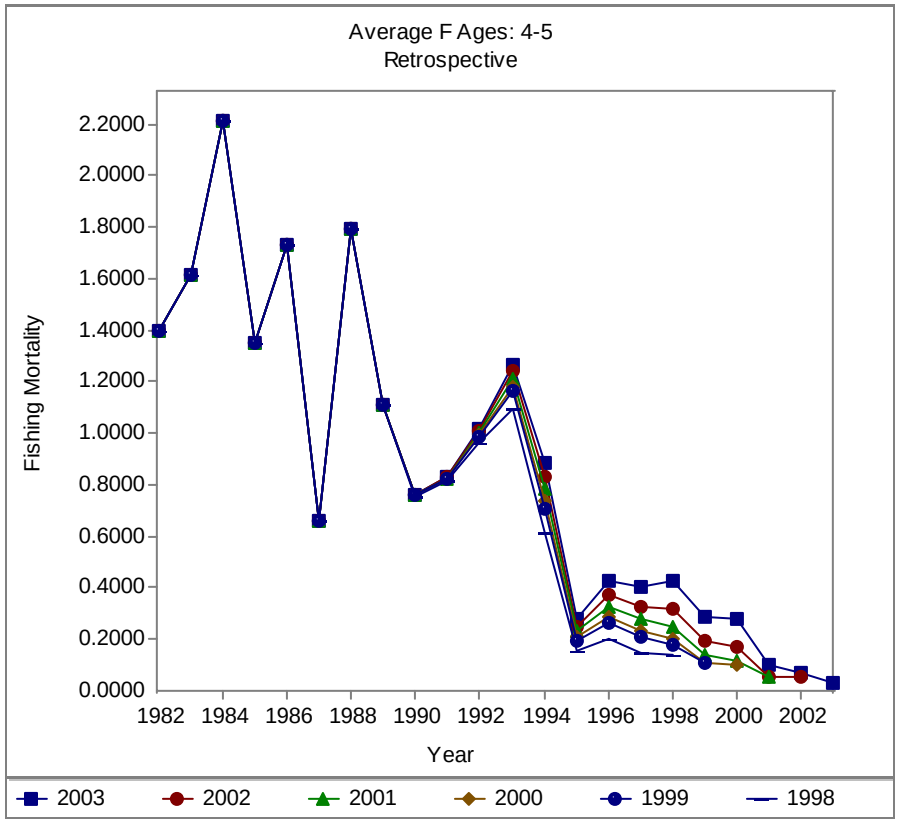



Figure 19. ADAPT run 24 retrospective pattern in fully-recruited F estimates.
The 1998 line shows estimated F when only data available through 1998 is used.
The 2003 line shows estimates when all data through 2003 is used.

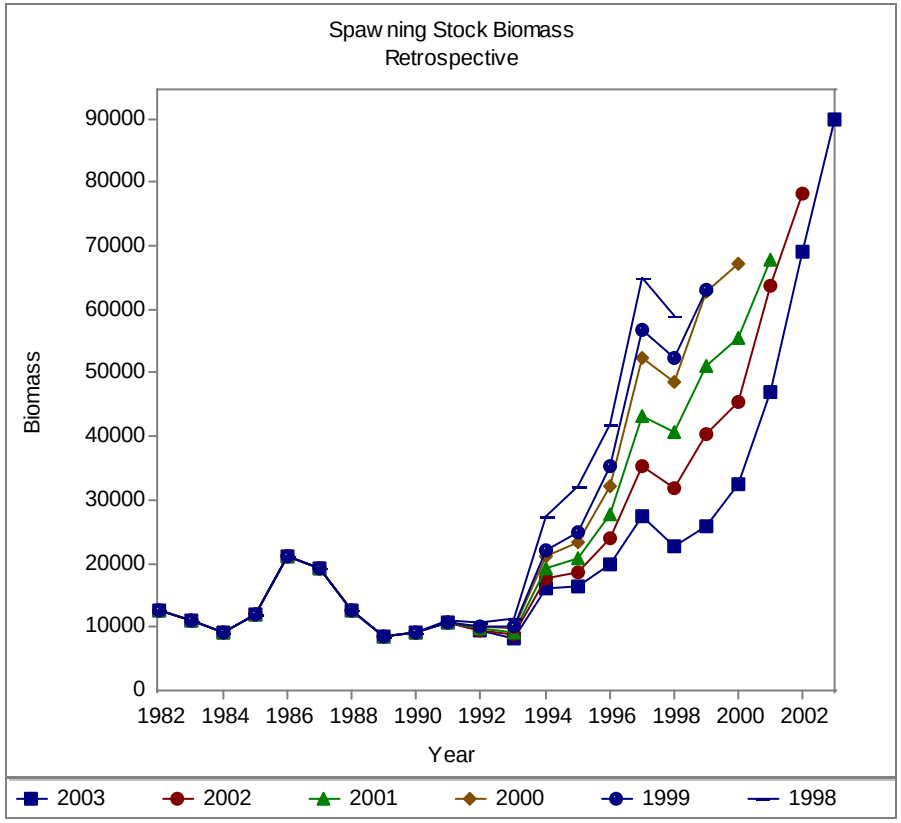



Figure 20. ADAPT run 24 retrospective pattern in estimated spawning stock biomass. Each line shows estimates when the label is the final year of data in the analysis.

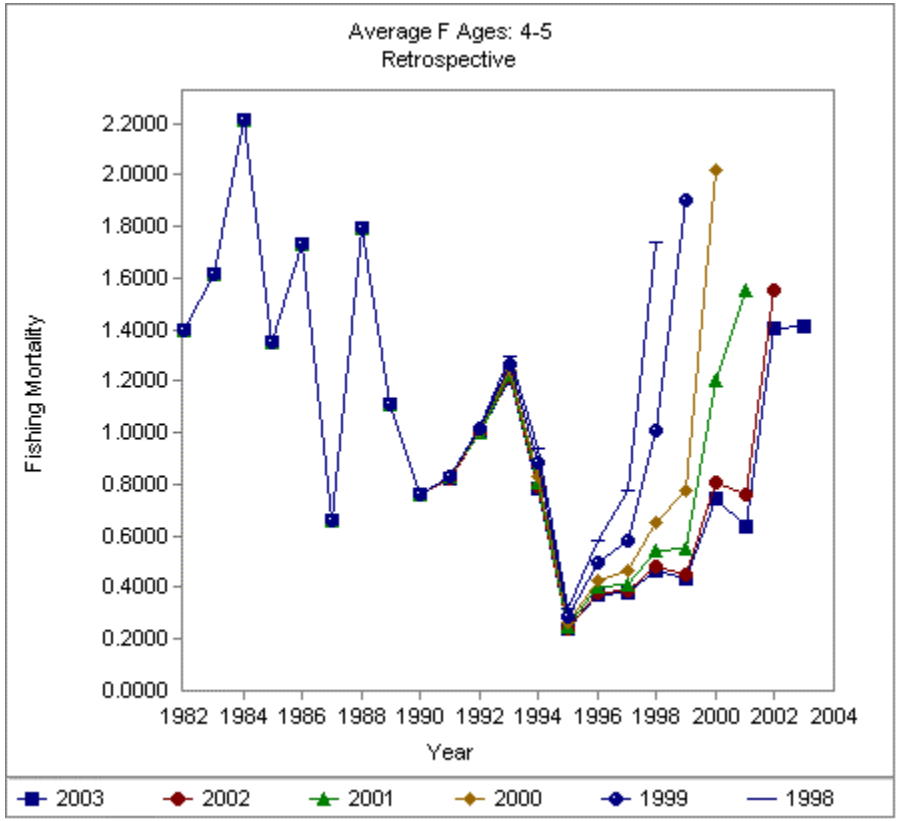



Figure 21. Run 14 retrospective pattern in fully-recruited fishing mortality.

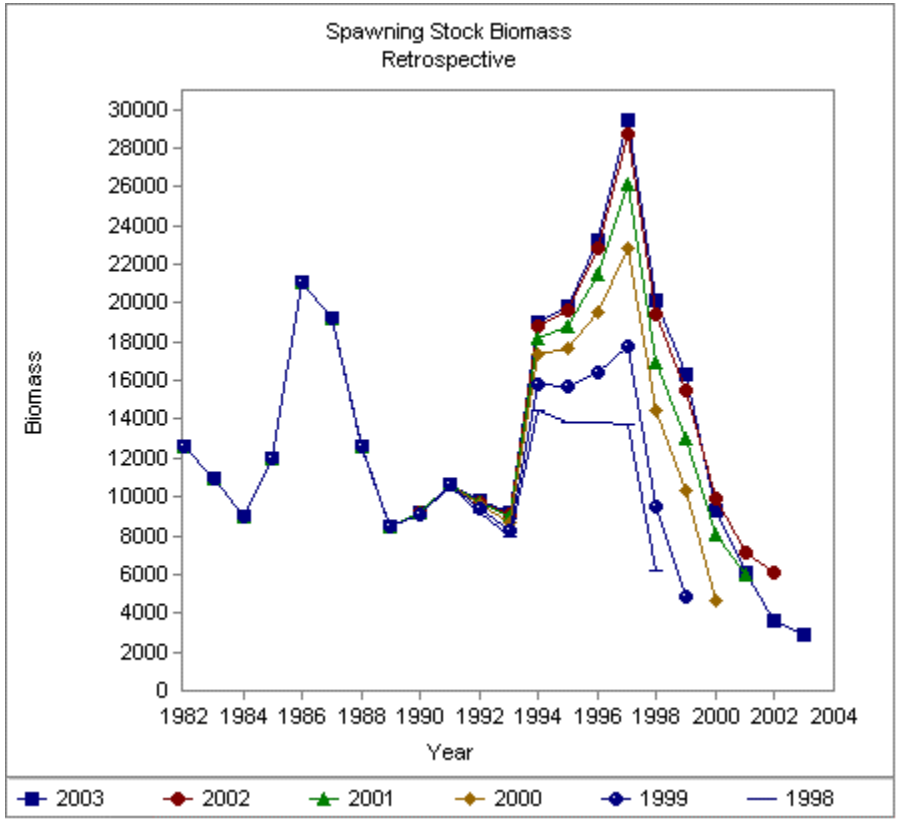



Figure 22. Run 14 retrospective pattern in spawning stock biomass estimates.

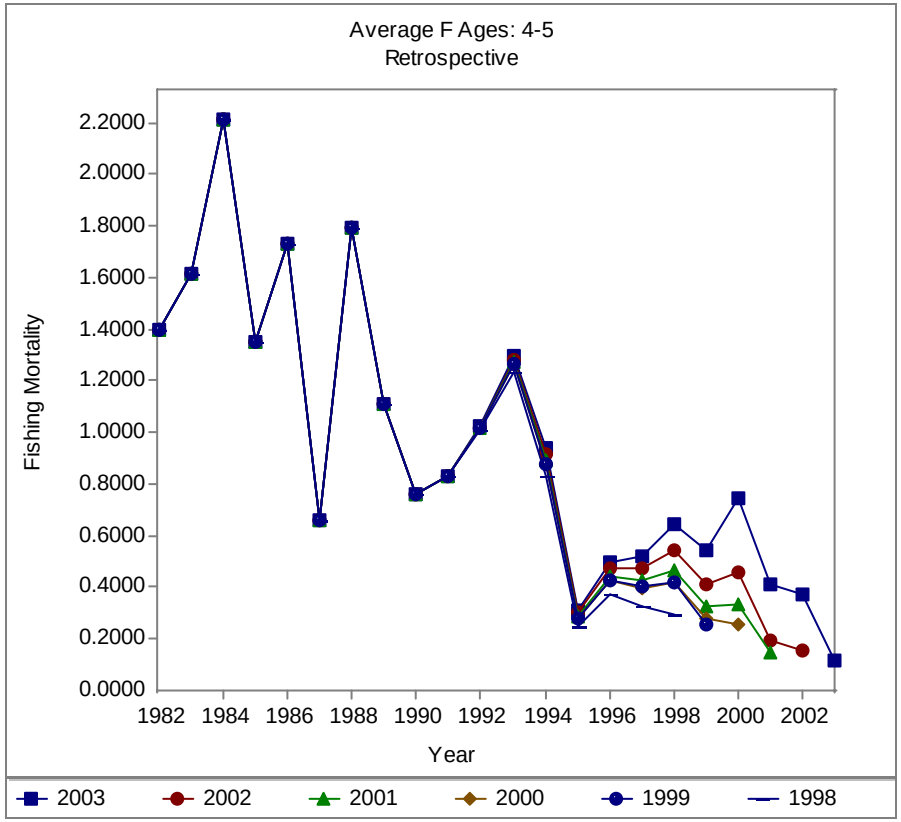
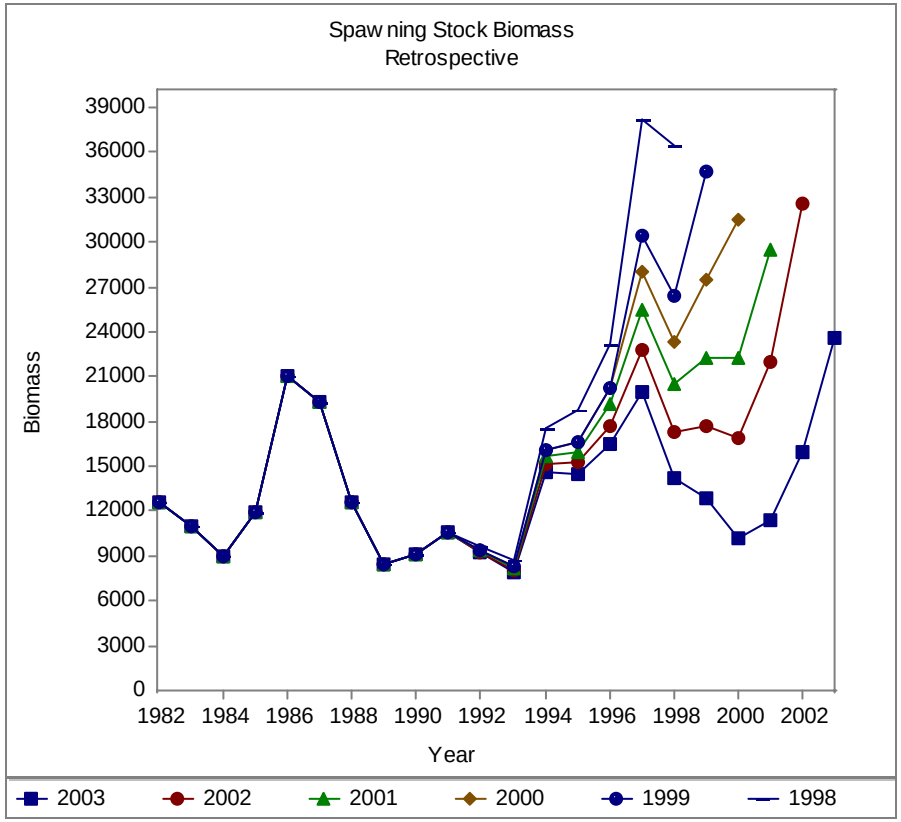



Figure 23A. Run 18 retrospective pattern for fully-recruited F.




Run 23B. Run 18 retrospective pattern in spawning stock biomass.

**Figure 24A. DEDFW Survey residuals from Run 18**

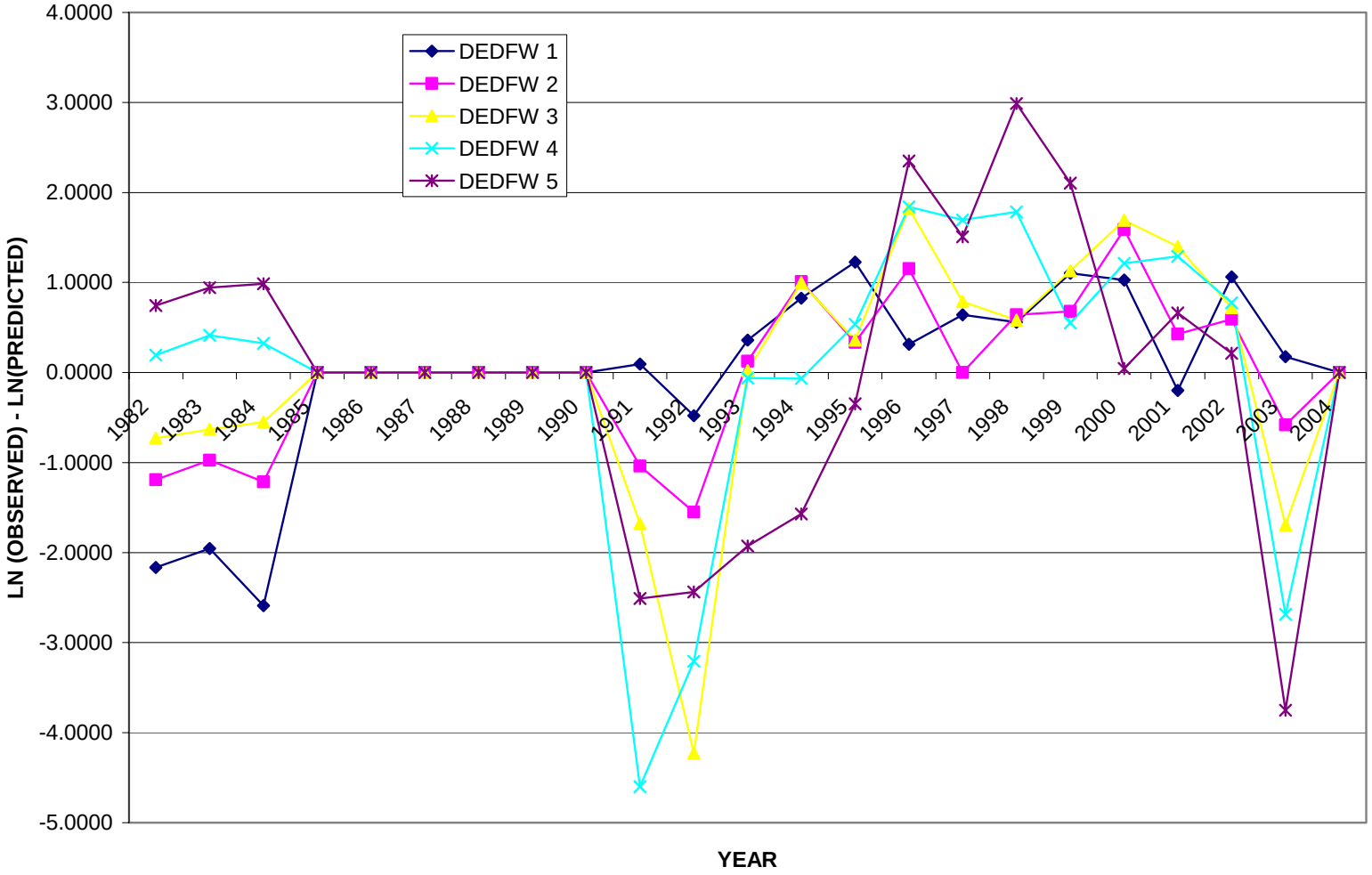


**Figure 24B. SEAMAP Residuals from Run 18**

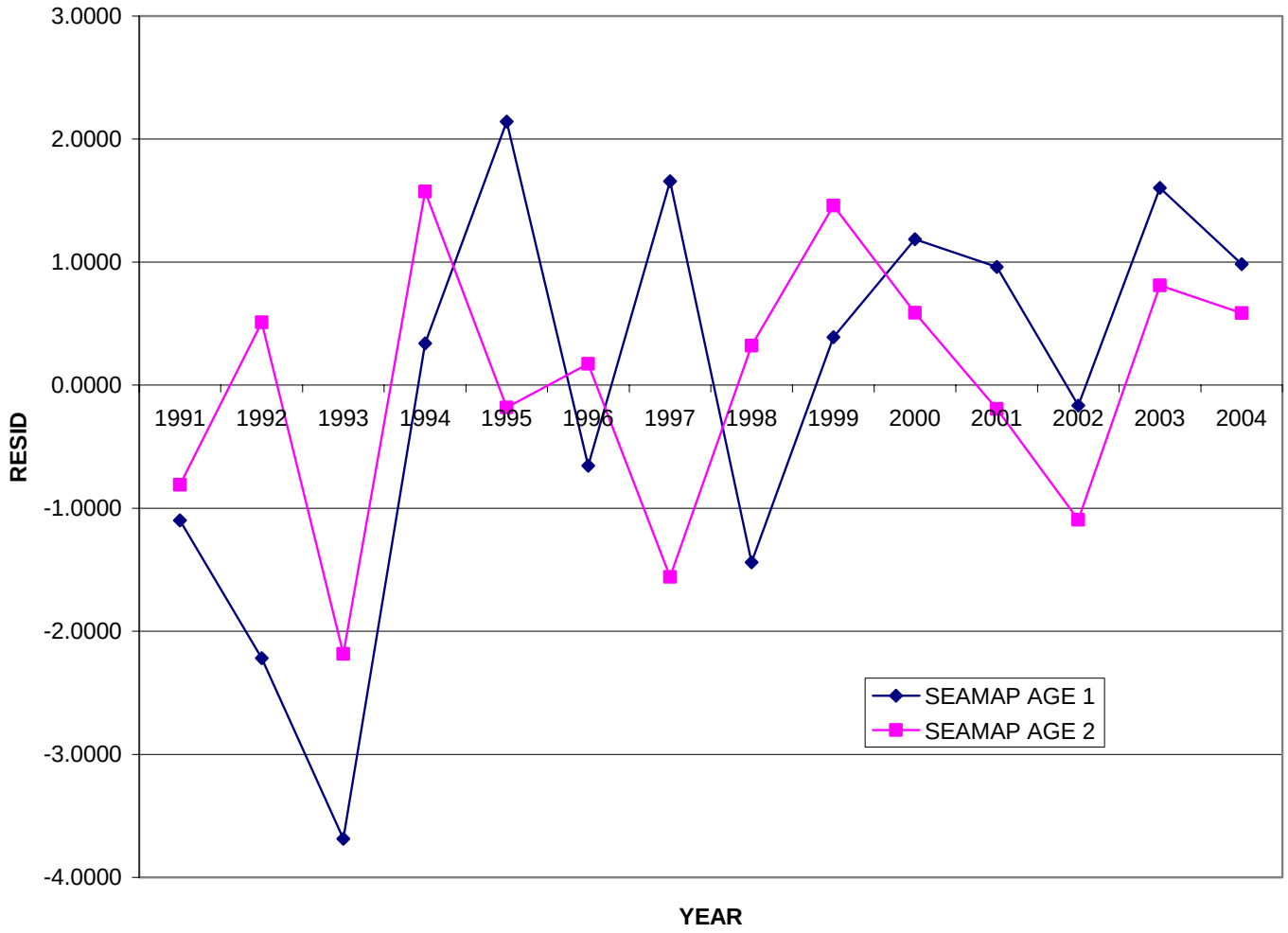


**Figure 24C. Residuals from recruitment indices, Run 18**

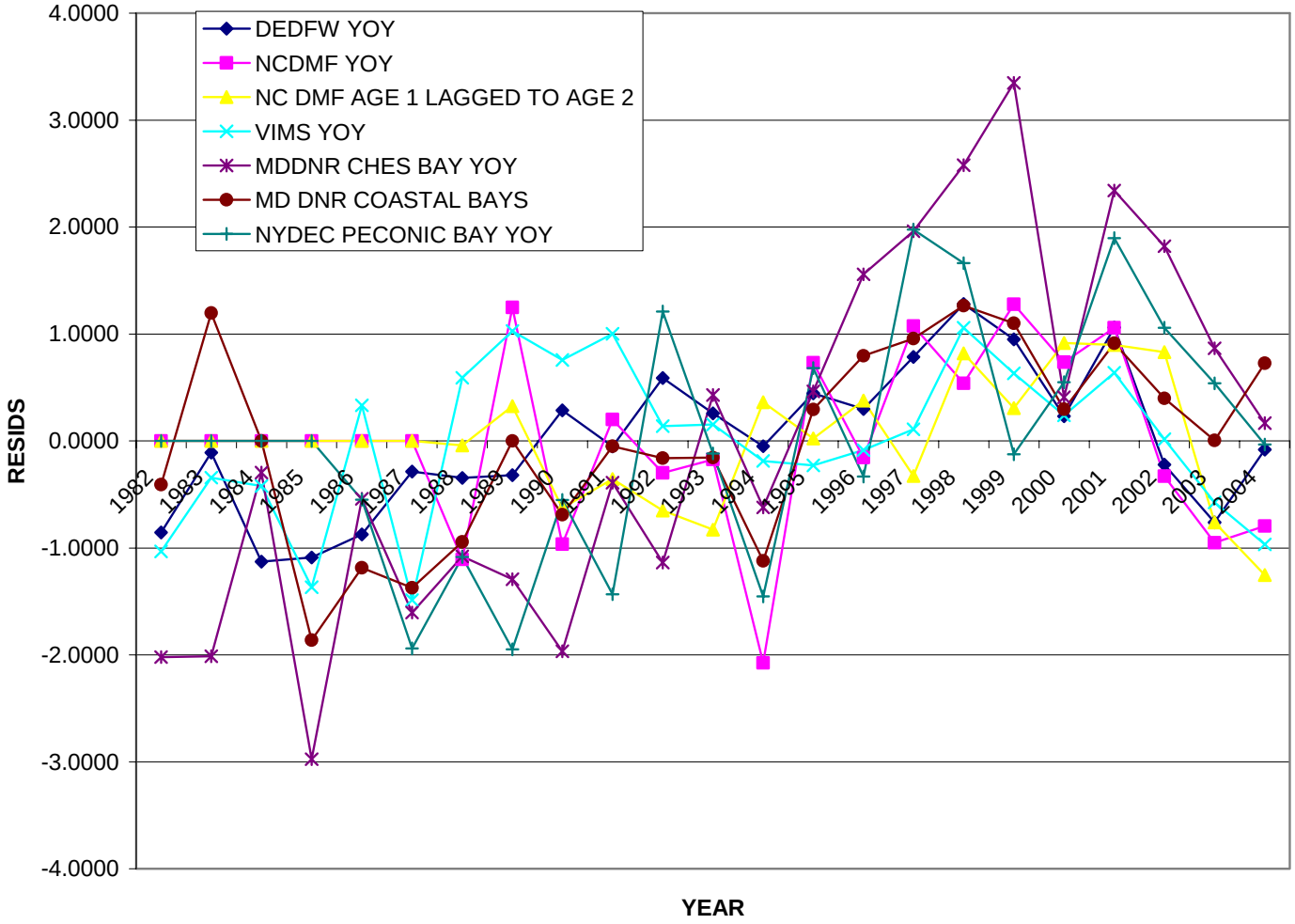


**Figure 24D. Recreational CPUE residuals from Run 18**

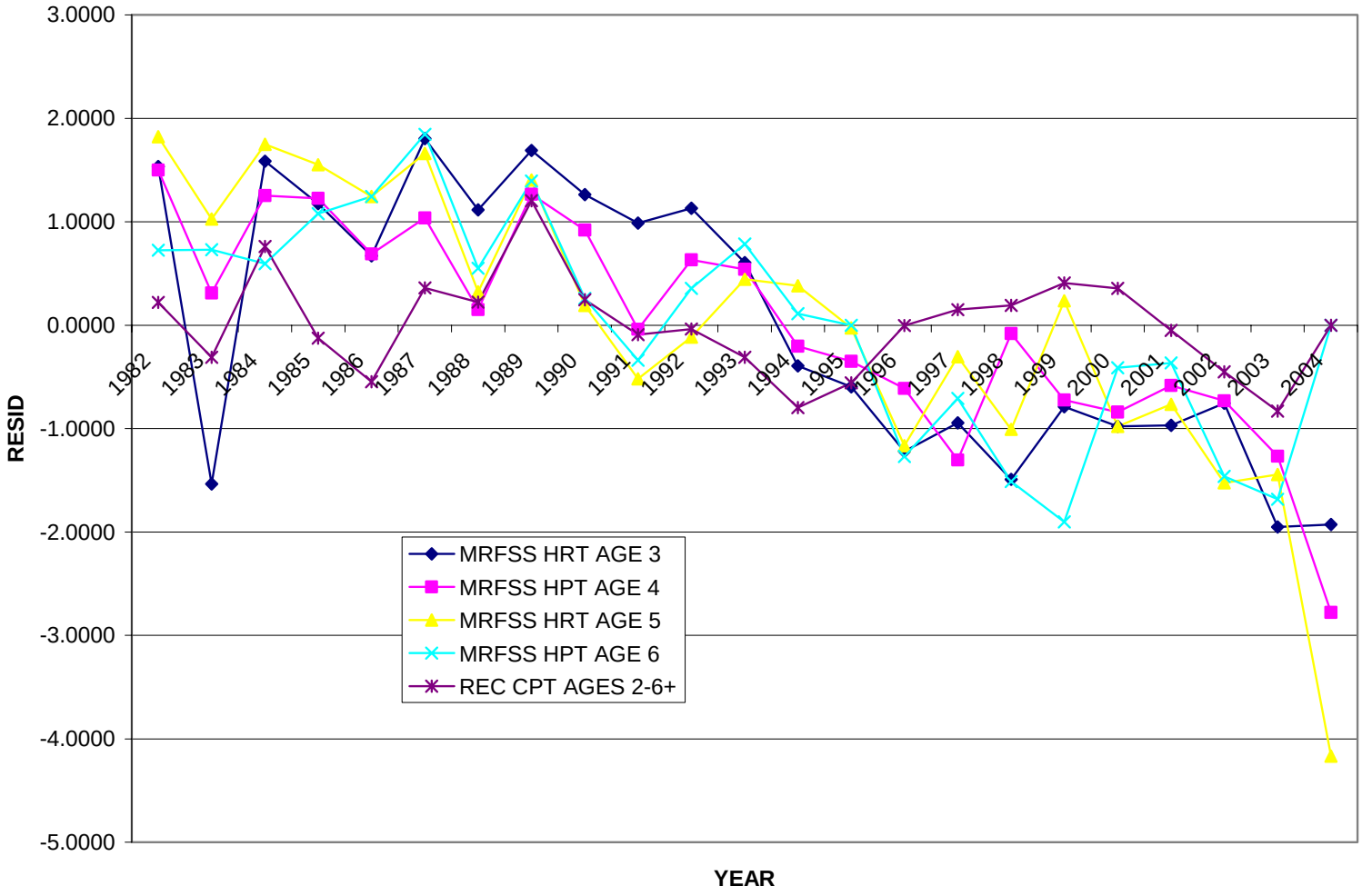


**Figure 25. Run 20 Retrospective Pattern in F**

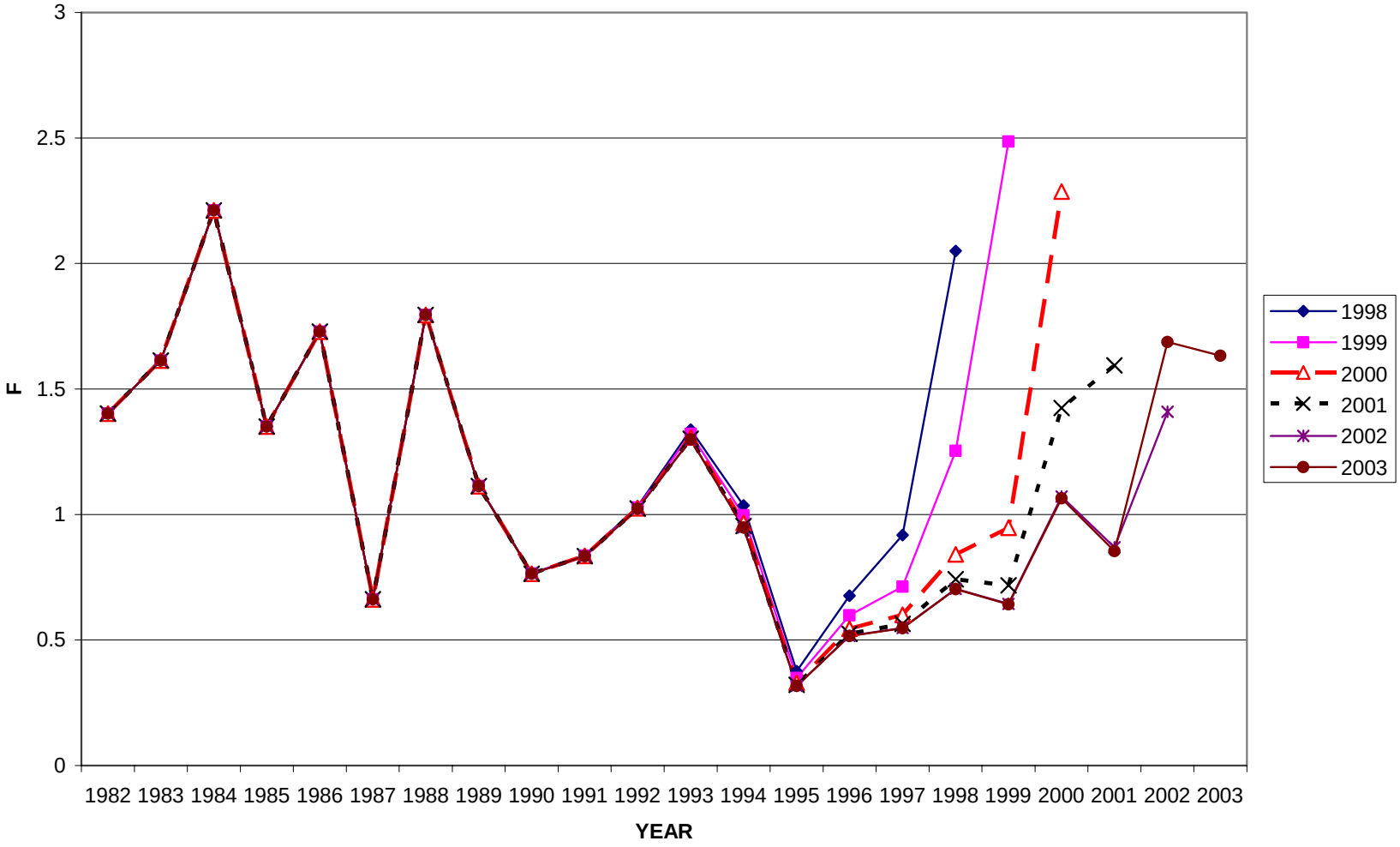


**Figure 26. Run 20 Retrospective Pattern in SSB**

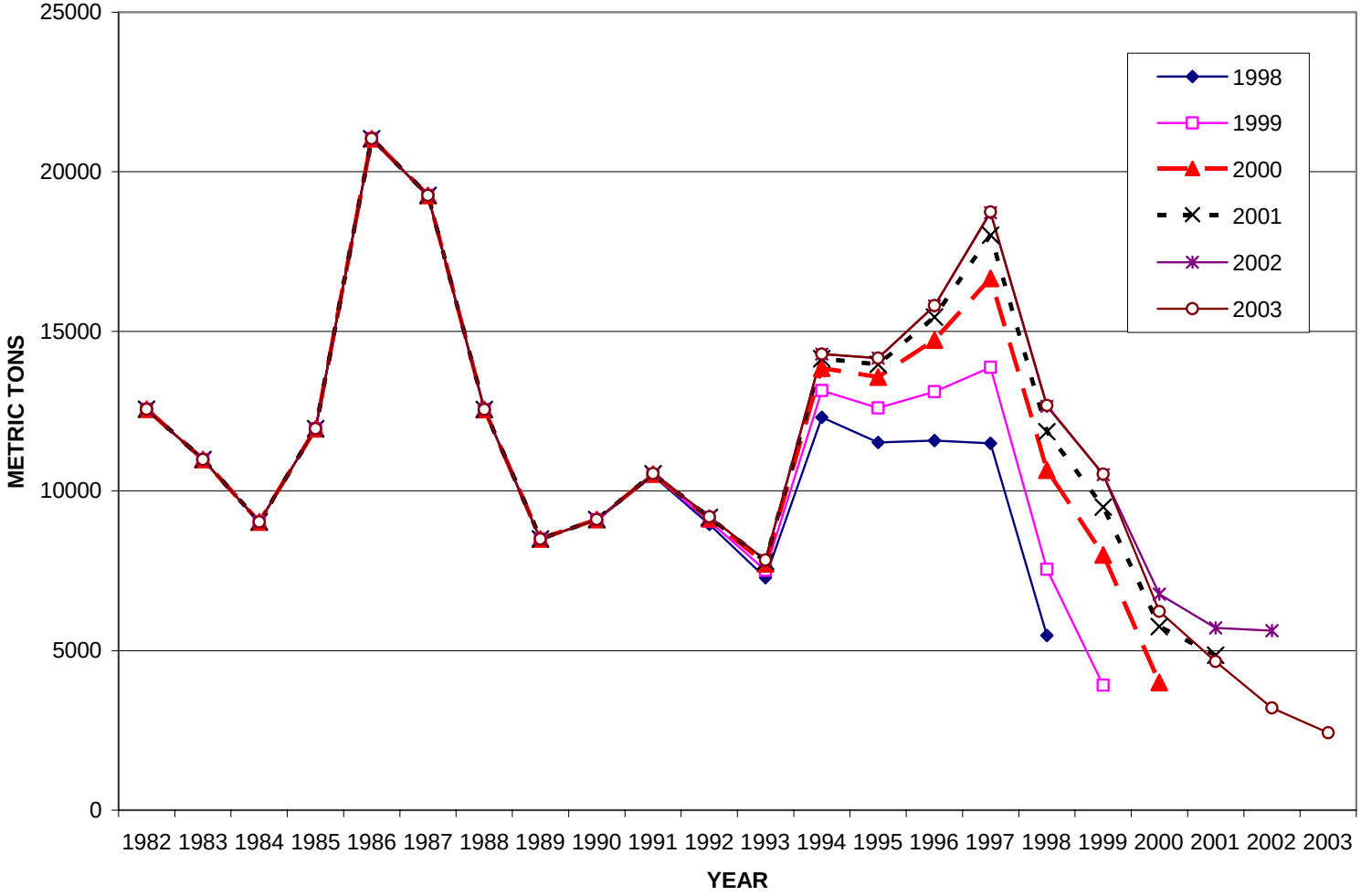


**Figure 26B. Run 20 residuals from recreational CPUE indices**

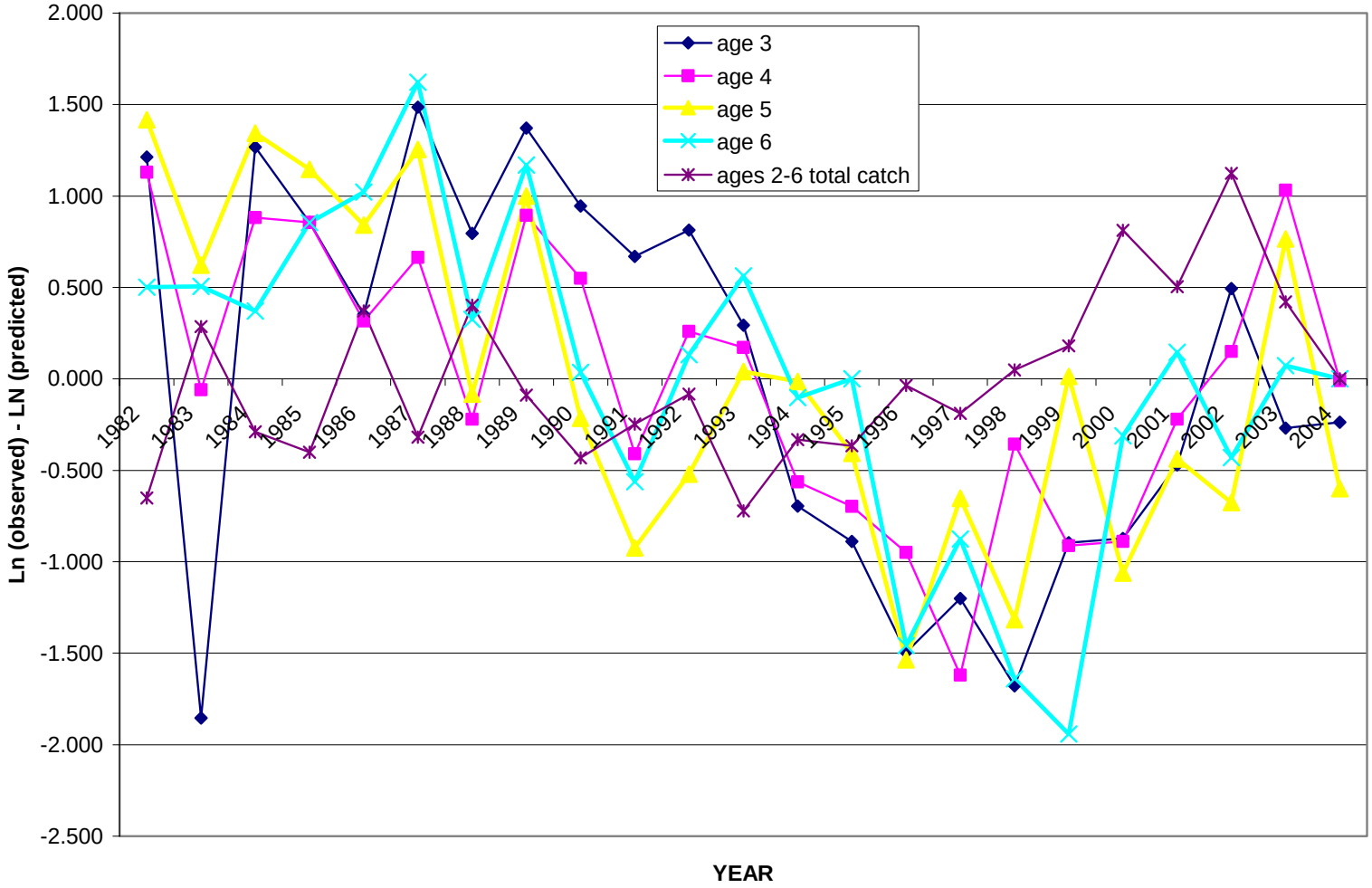


Figure 27. Delaware and New Jersey trawl survey Quality+ PSD

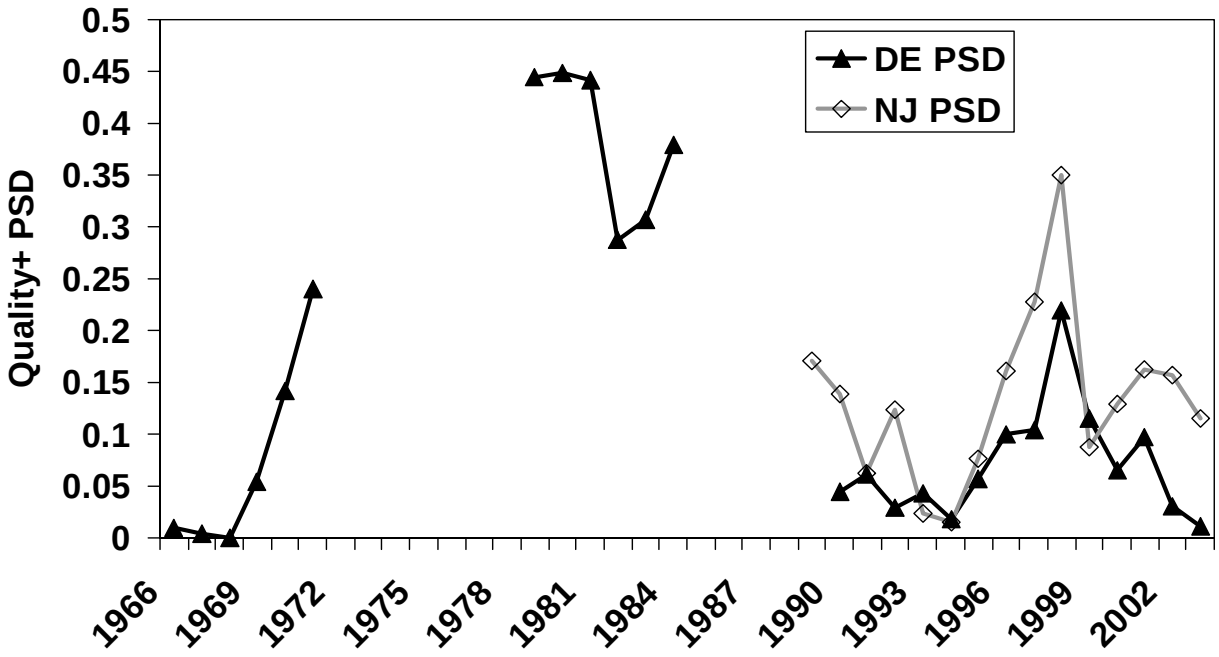


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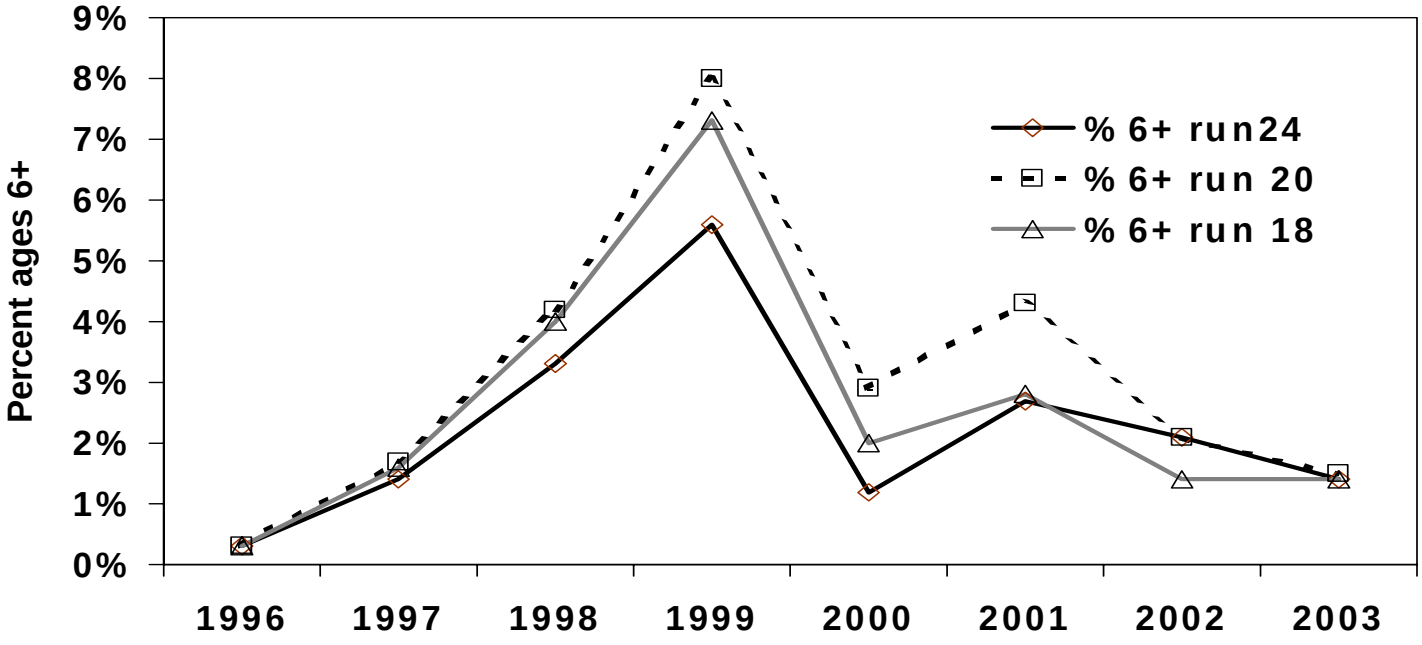
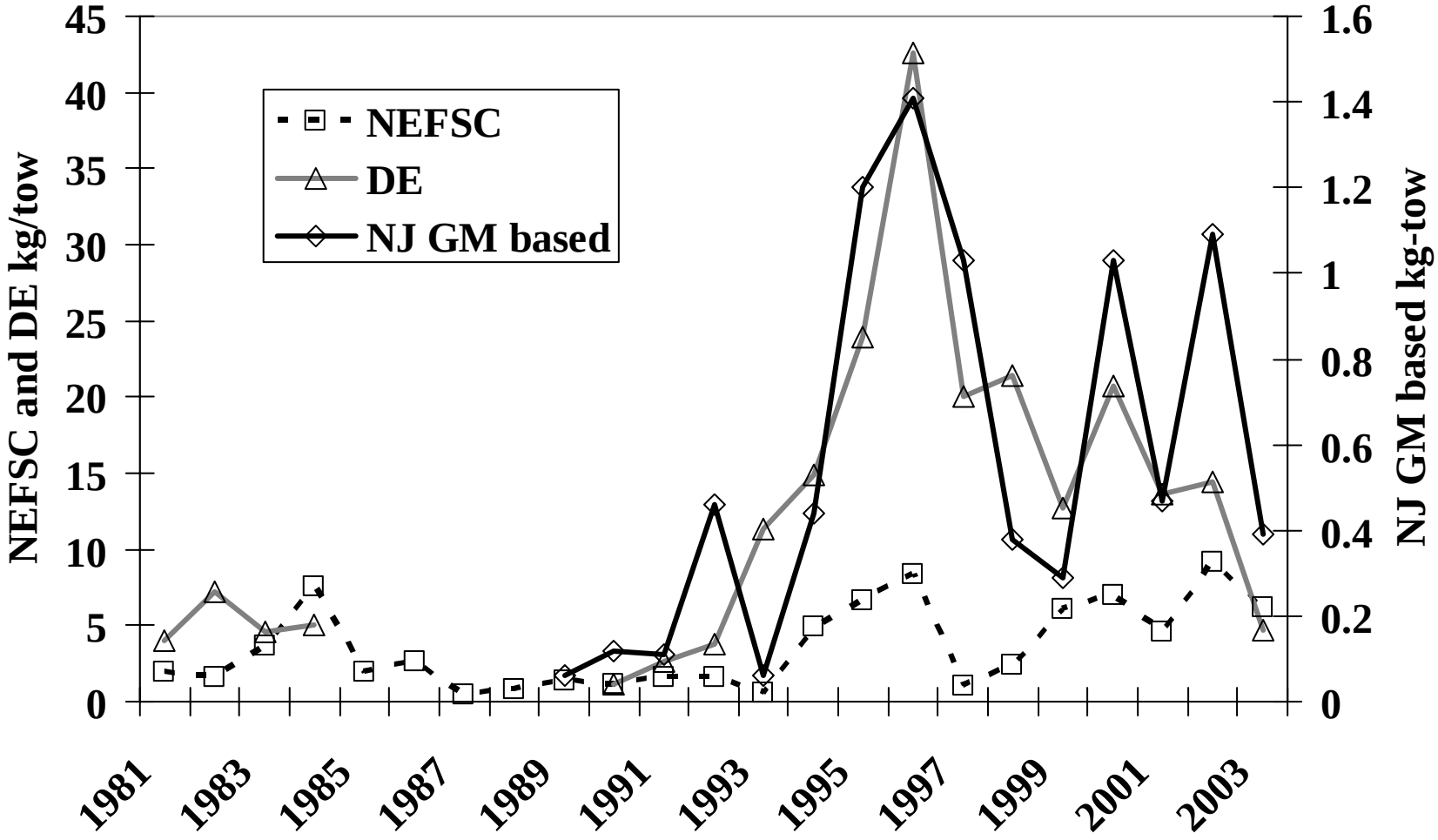
**Figure 27a. Percent of population estimate that was ages 6 and older in three ADAPT VPA runs.**



# Figure 28. Trawl survey biomass indices (kg/tow of 25 cm + weakfish)



# Figure 29. Model results based on trawl survey indices: F and biomass estimates with and without discards

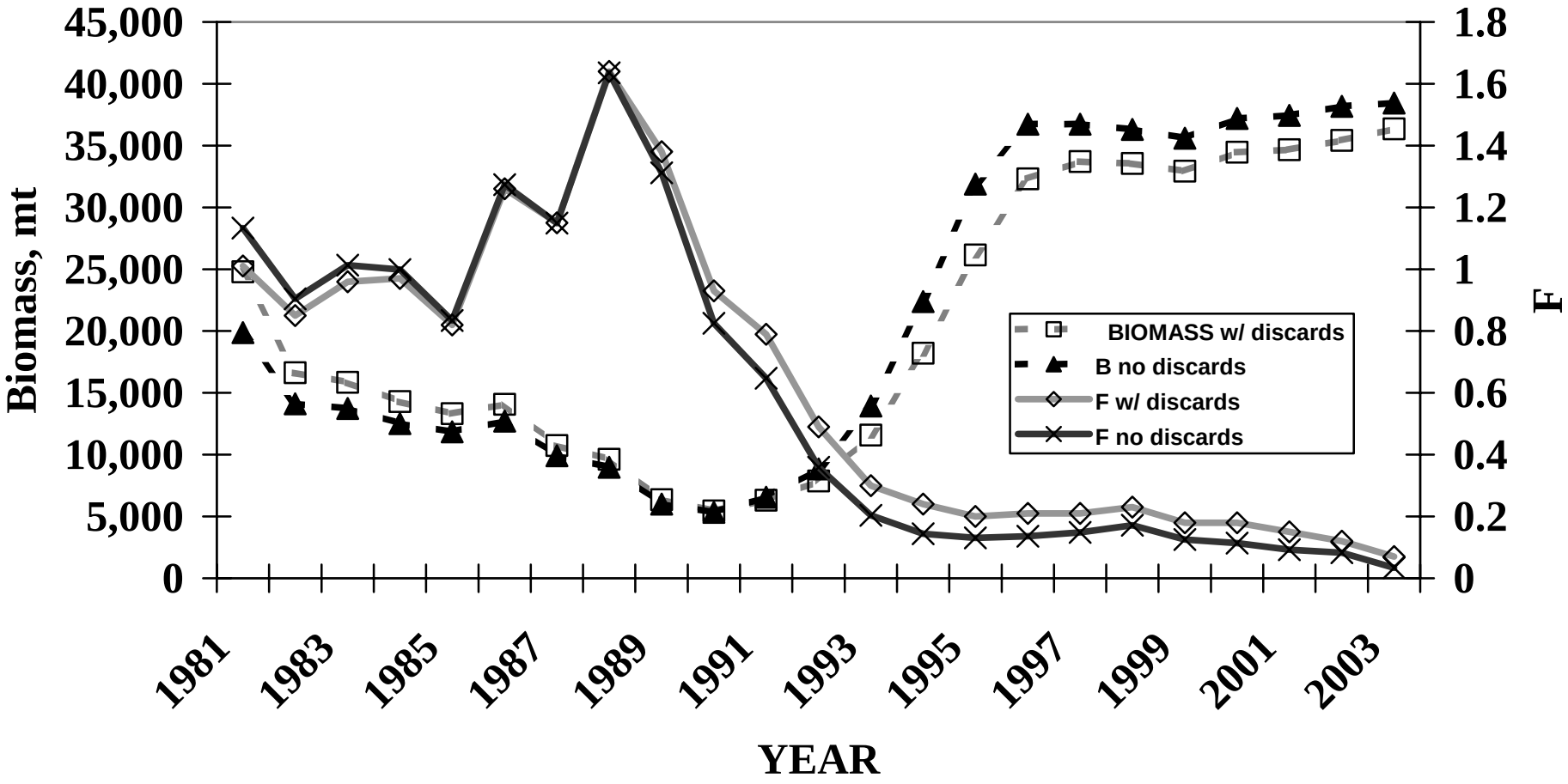


Figure 32. Standardized age 0 weakfish indices. Nj (grand mean) indicates general trend.

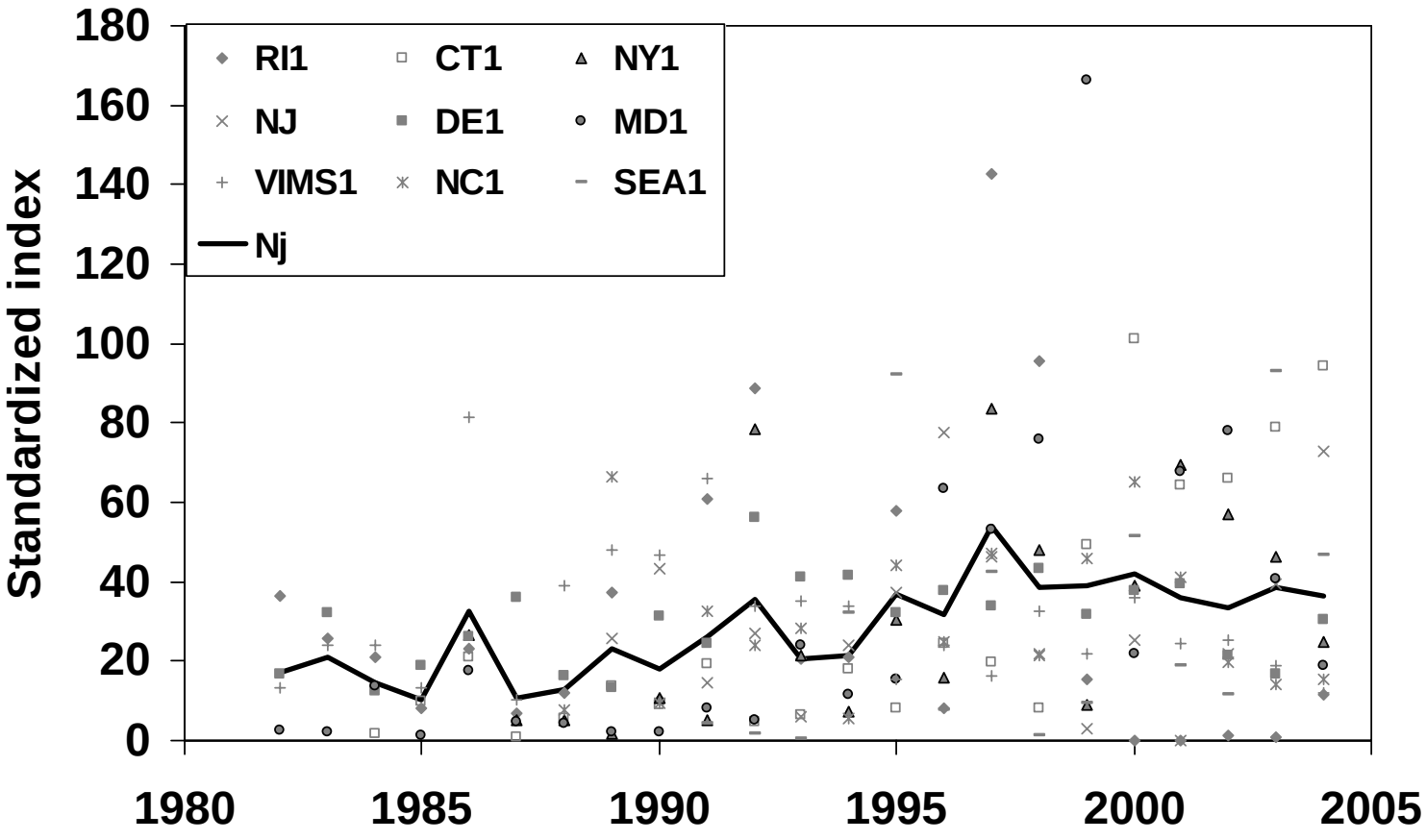


Figure 33. Trends in age 0 (Nj), age 1 (Ny), and age 0-1 total mortality (RZj) indices.

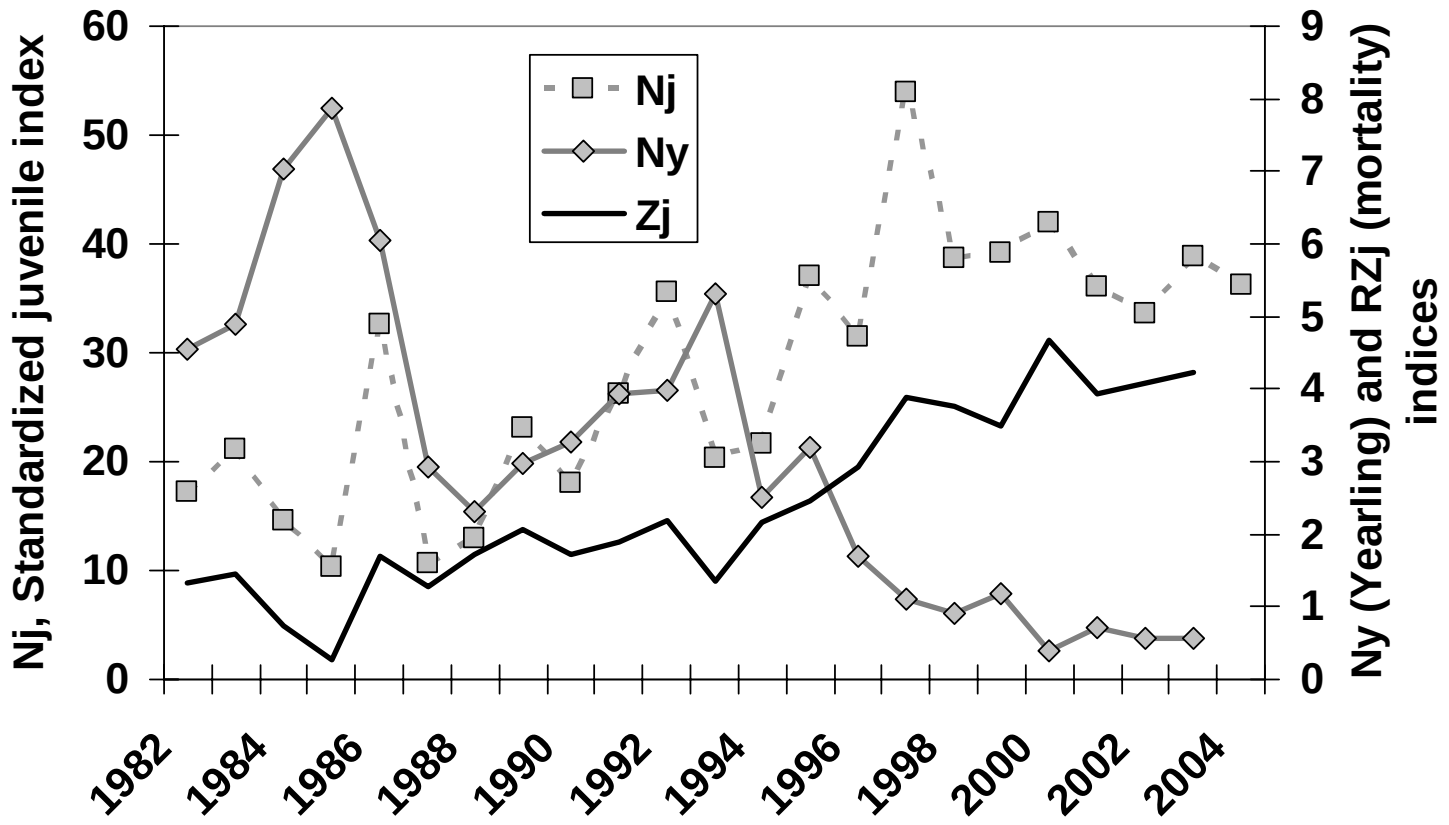


Figure 34. Trends in $M_{Wt.}$

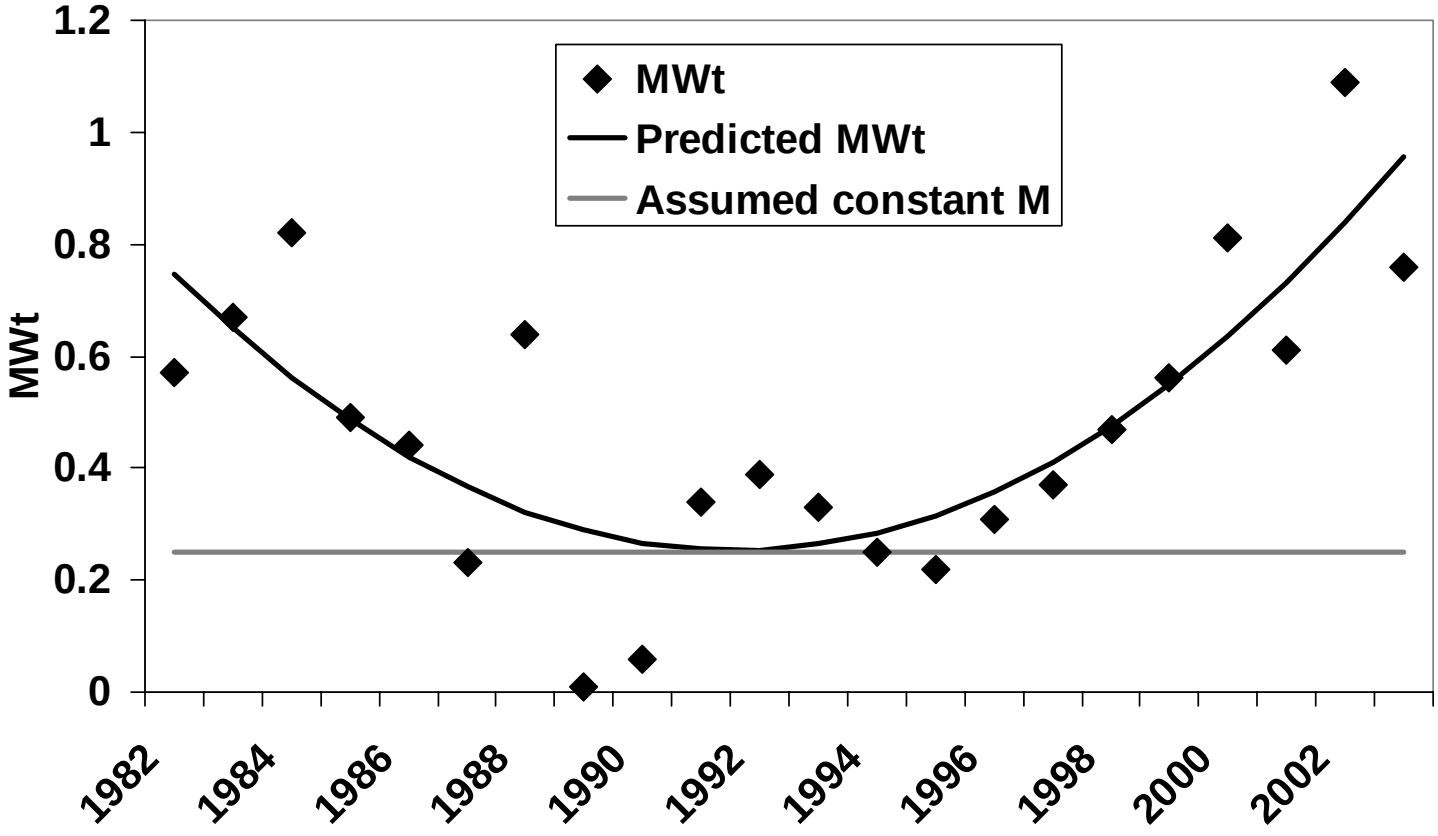


Figure 35. Juvenile weakfish mortality index (units arbitrary) and VPA-based estimates of biomass of ages 8+ striped bass.

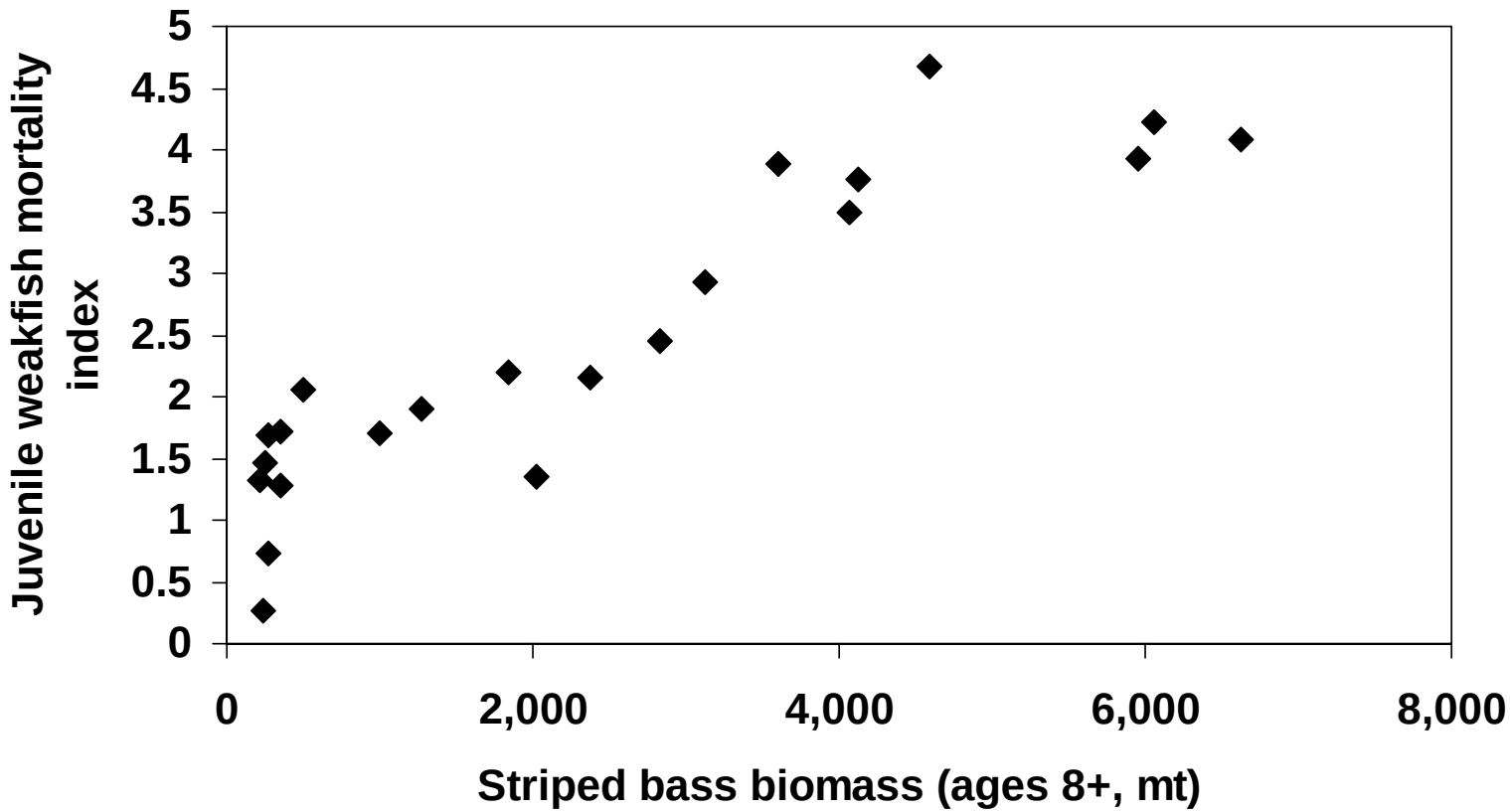


Figure 36. Gompertz striped bass-weakfish predator-prey model estimates of F, $F_{msy}$, $M_p$, and $M_{vpa}$. Model with iterative reweighting was used.

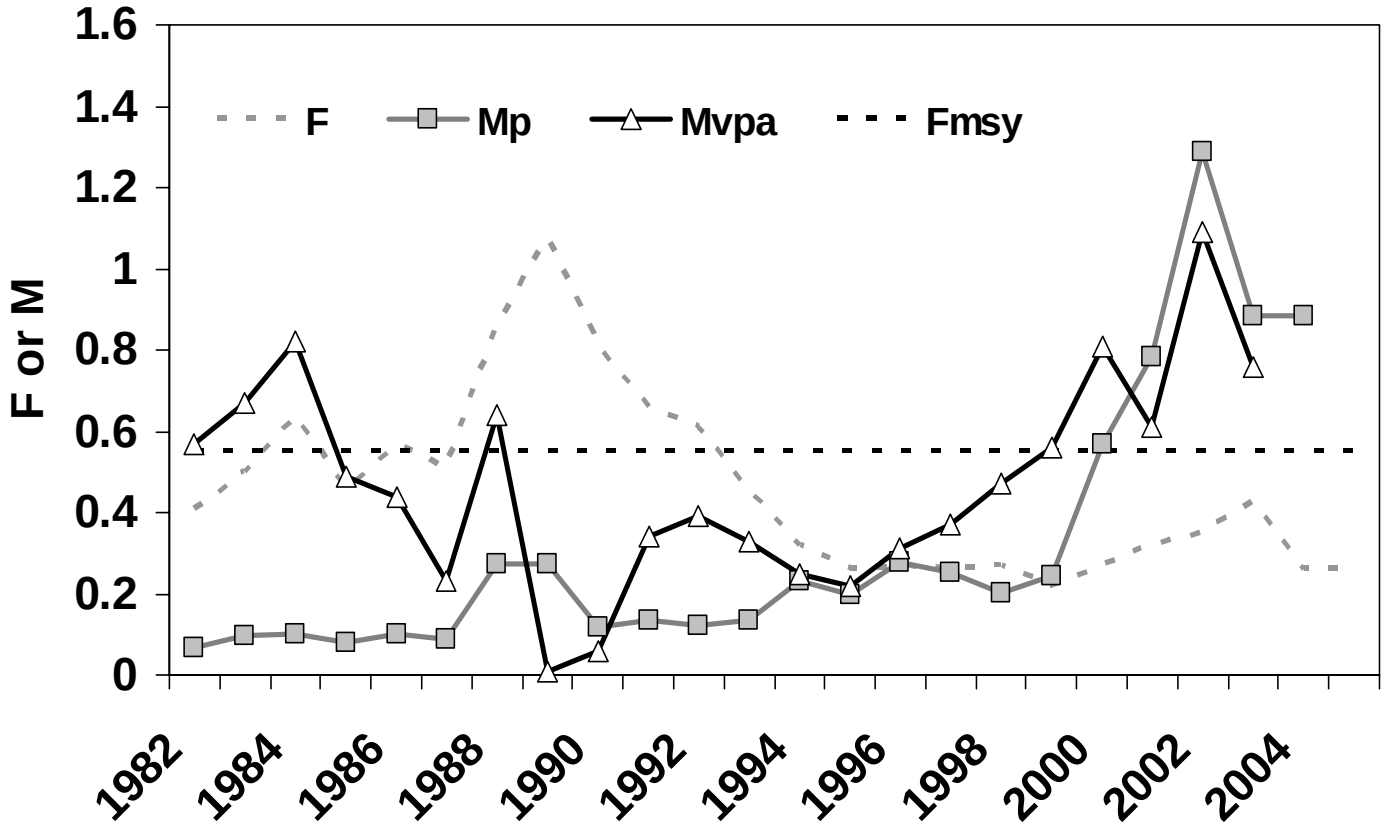


Figure 37. Gompertz surplus production model estimate of weakfish biomass with and without striped bass predation terms. IR indicates iterative reweighting was used in the fitting process.

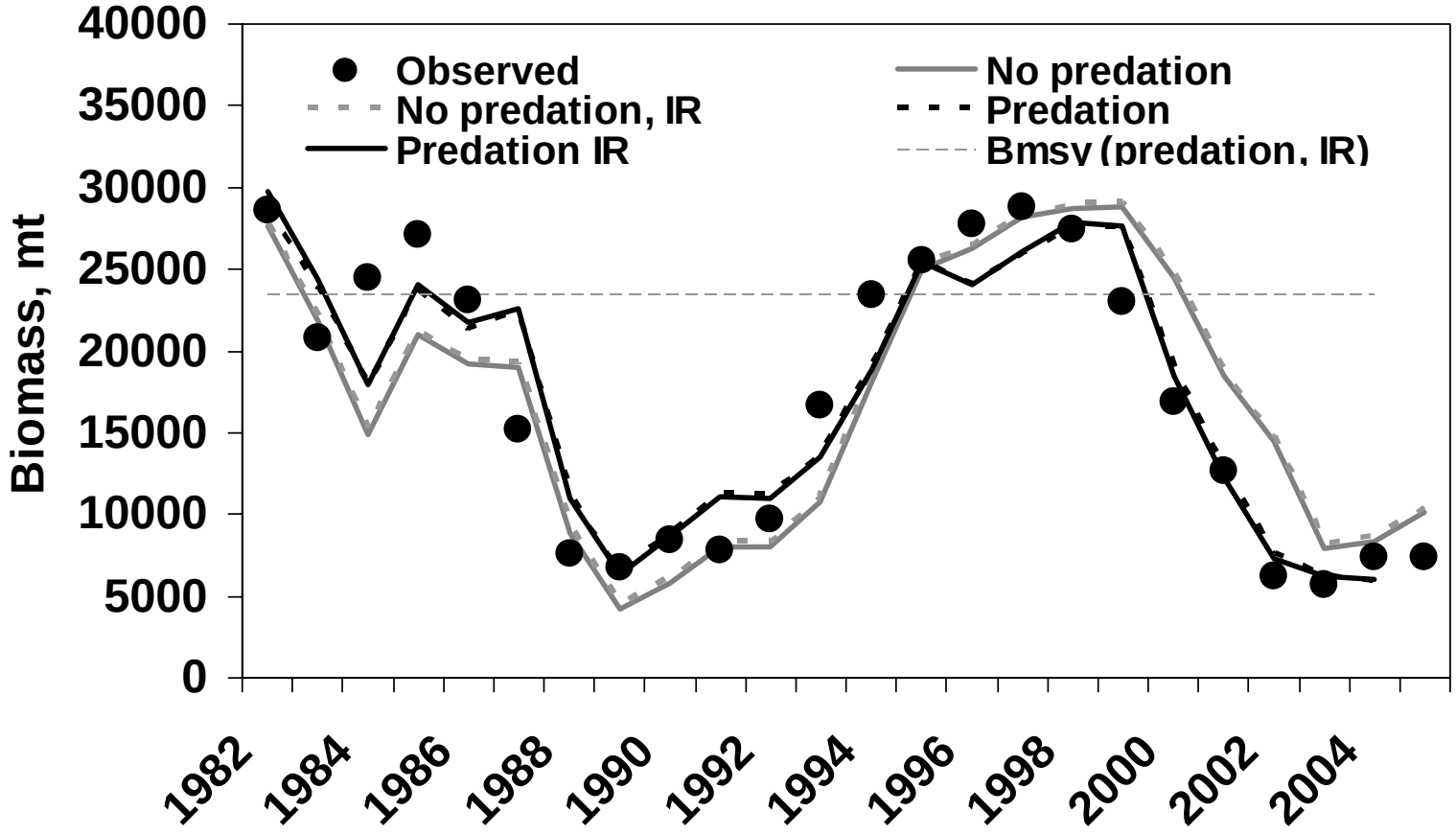


Figure 38. Observed (average biomass; Crecco 2005) and biomass predicted by external production model with varying M and F.

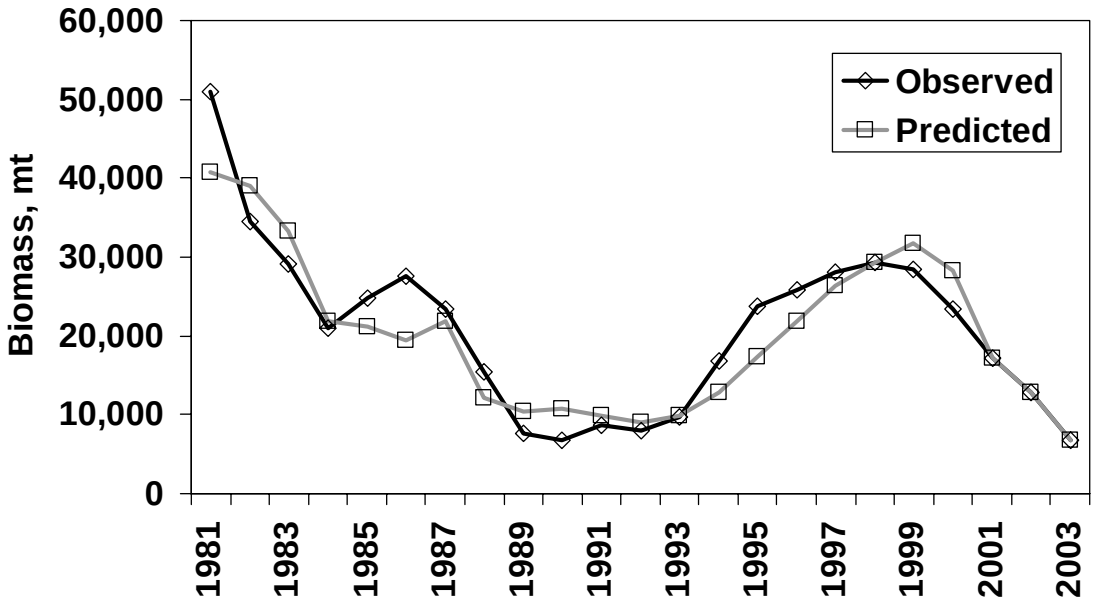


Figure 39. Trends in estimated F and M from external production model without an ecological stability assumption.

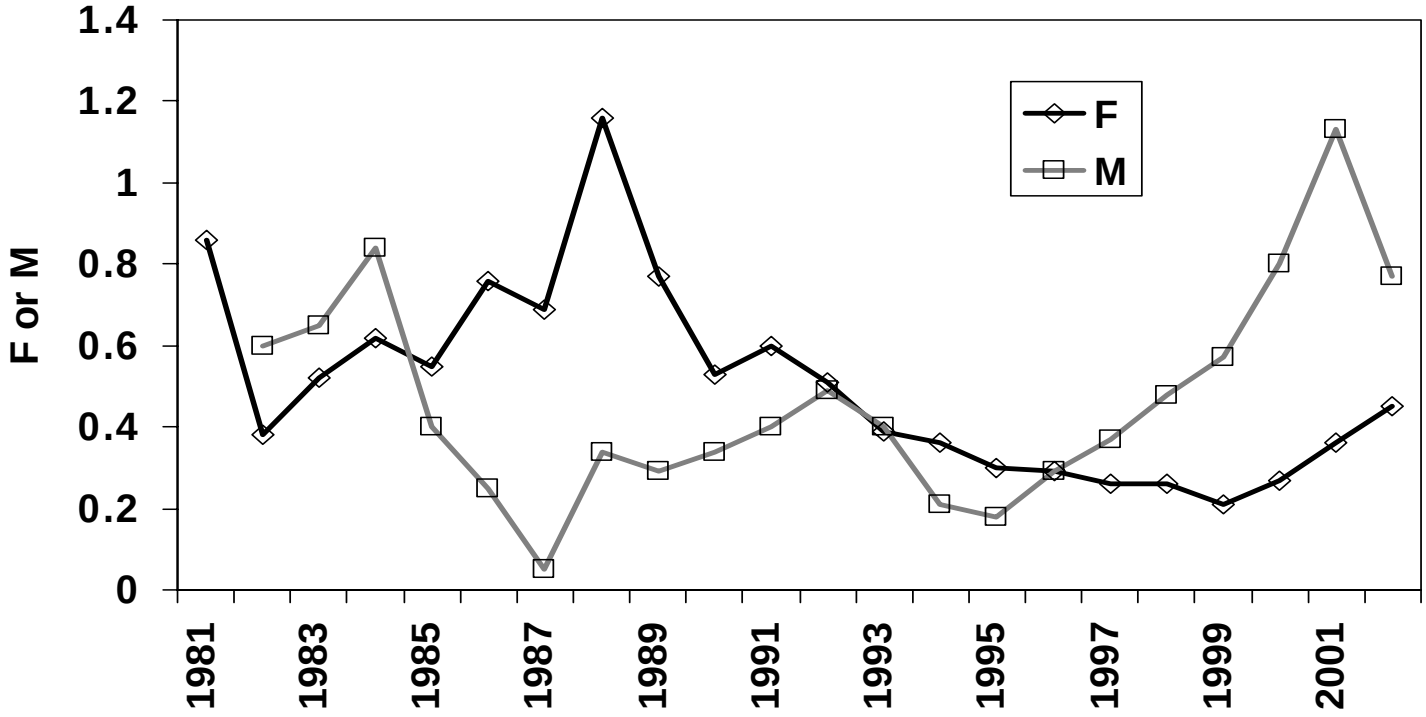


Figure 40. Estimated weakfish biomass during 1981-2003 based on different assumptions. All versions were "forced" to converge with 2001-2003 estimates of Crecco (2005). See Table 1 for model details. The 3 parameter model is the base model.

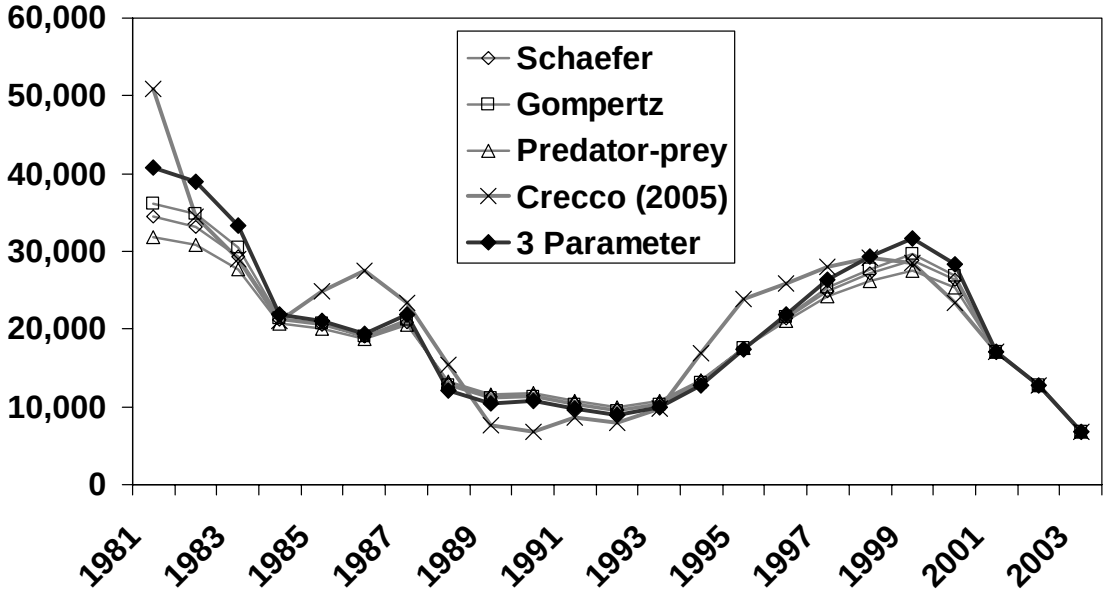


Figure 41. Estimates of F under different model conditions. See Table 1 for model details. All versions were "forced" to converge with 2001-2003 estimates of Crecco (2005). The 3 parameter model is the base model.

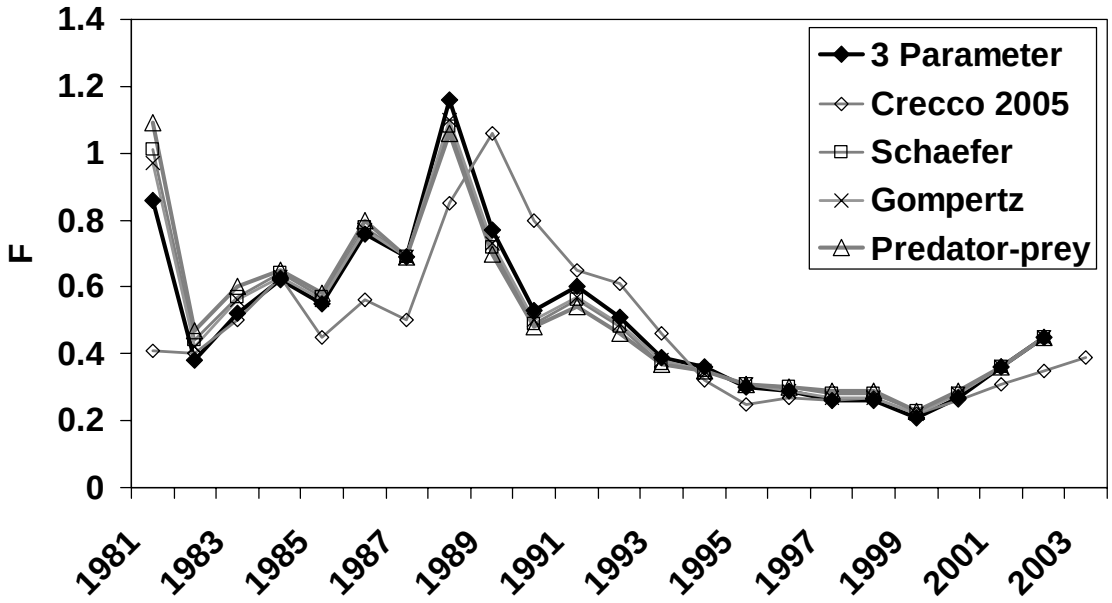


Figure 42. Estimates of M under different model conditions. See Table 1 for model details. All versions were "forced" to converge with 2001-2003 estimates of Crecco (2005). The 3 parameter model is the base model.

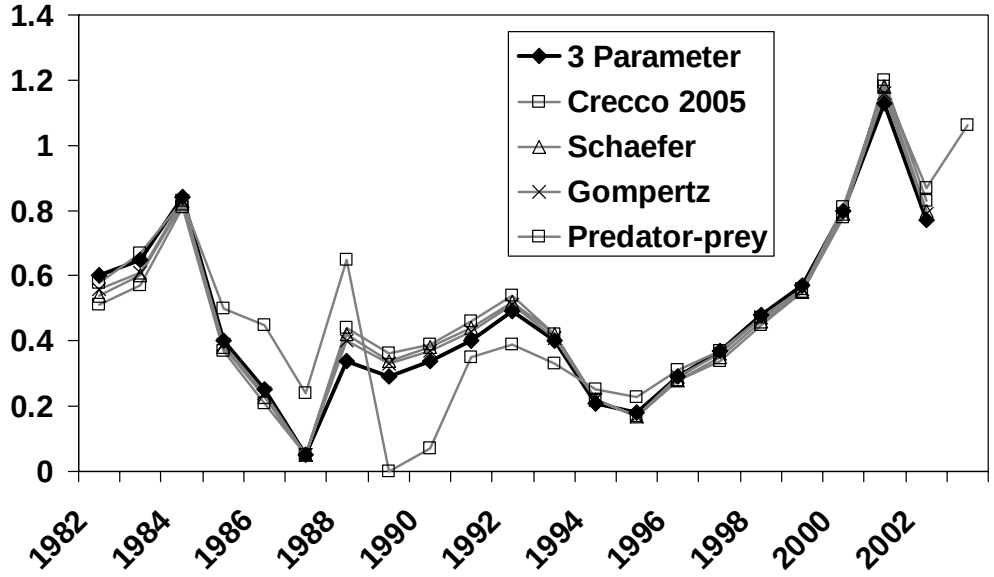


Figure 43. Projected weakfish biomass without a reduction in F (F = current), with F cut by 25%, 50%, and 75%, and a complete moratorium (discard mortality = 0) when M is kept at its current level.

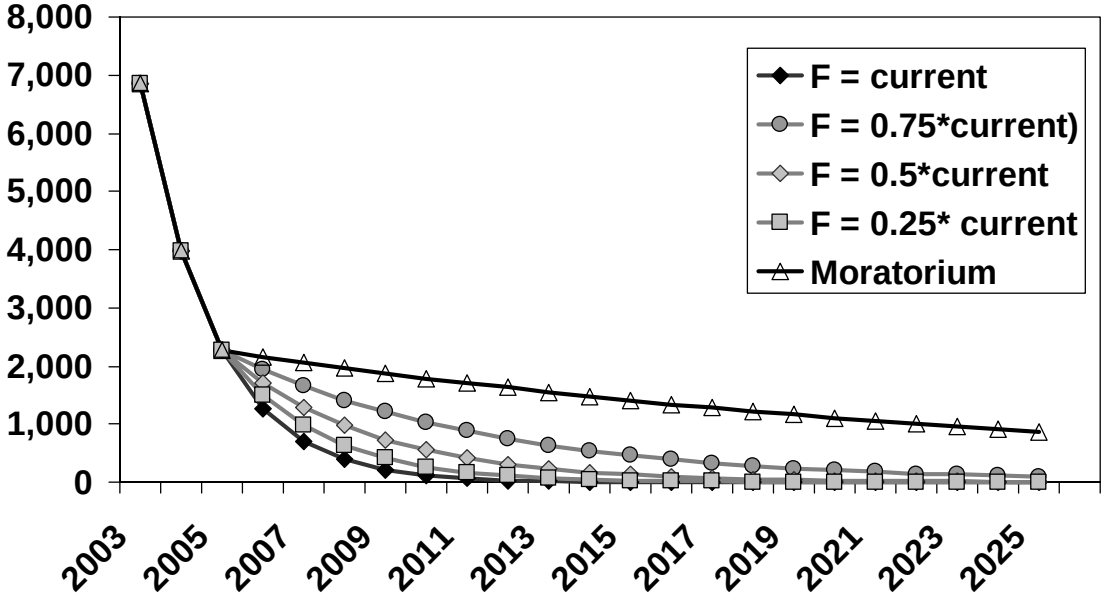


Figure 44. Projected weakfish biomass with reduction in Z equivalent to 1.5 * F or 2.0* F after 2005. See Table 1 for model details. Recovery is indicated at mean 1998-2000 biomass (29,785 mt).

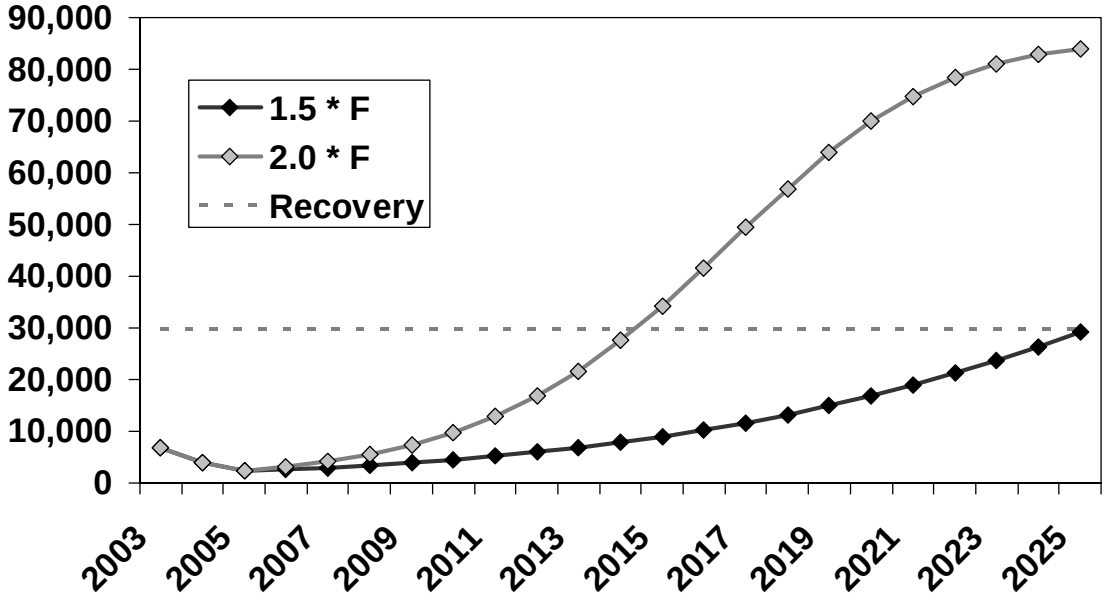


Figure 45. Projected biomass with no reduction in current F or cuts of 25%, 50%, or 75% when M depreciates from 0.95 in 2006 by a constant coefficient (0.8) to a base level (Mb = 0.25). Recovery is indicated at mean 1998-2000 biomass (29,785 mt).

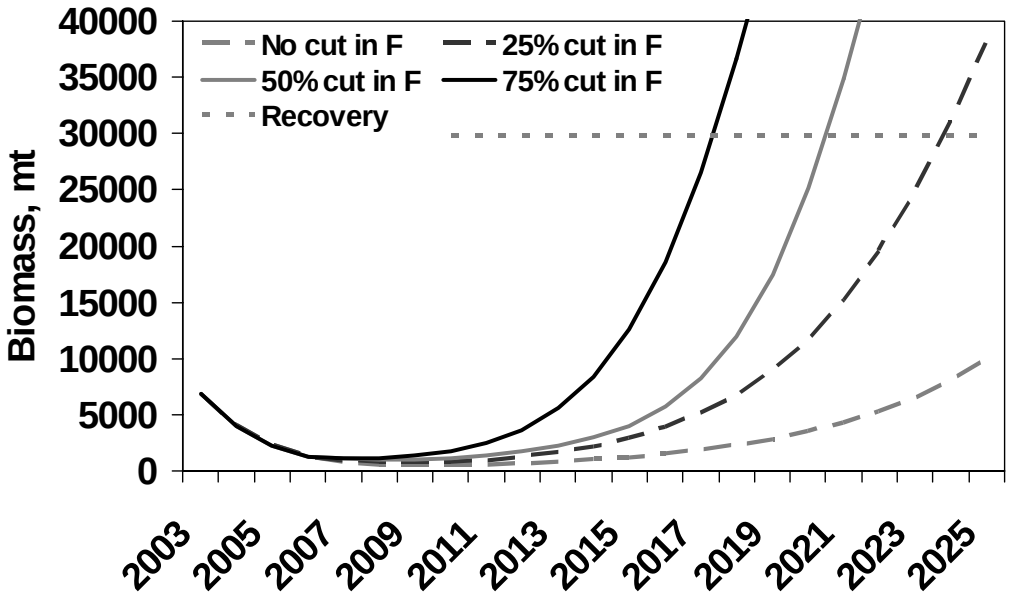
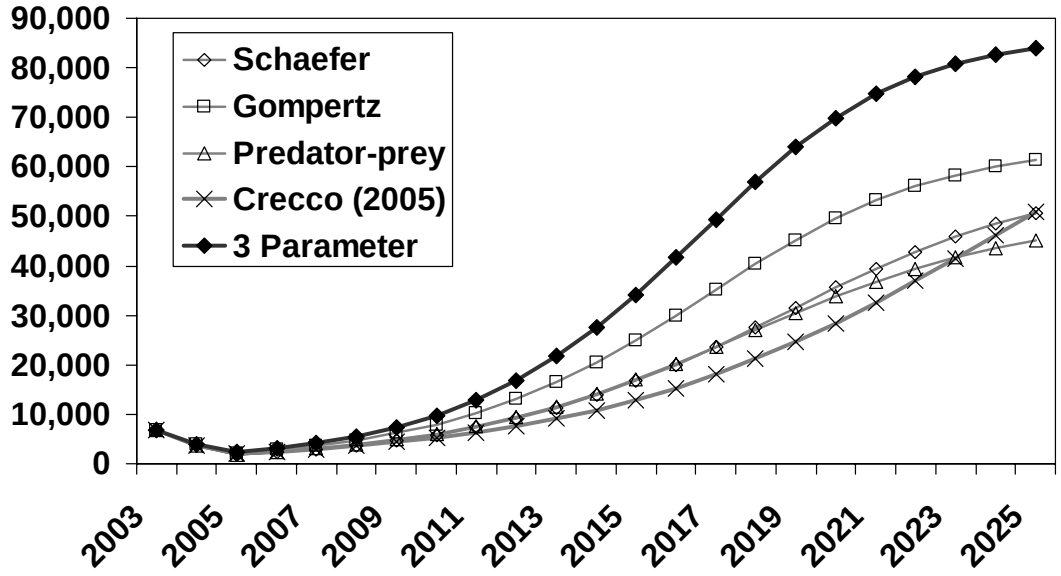


**Figure 46. Projected weakfish biomass with reduction in Z equivalent to 2.0 * F. See Table 1 for model details. Recovery occurs in 2016 for the Schaefer, 2014 for Gompertz, 2015 for predator-prey, 2020 for Crecco (2005), and 2014 for the base model.**



# WEAKFISH STOCK ASSESSMENT REPORT FOR PEER REVIEW (PART 2)

## An Ecological Assessment of Weakfish: Examination of Fishing and Trophic Effects on the Recent Stock Decline

February 2006

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Note: an external peer review panel did not endorse the recommendations within this assessment report. For more information see the Peer Review Report (Section B), and the Weakfish Technical Committee's responses to that report (Section C).

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## INTRODUCTION

Weakfish fisheries were subject to increasingly restrictive management during the early and mid-1990s (ASMFC 2002). After imposition of Amendment 3 in 1996, weakfish were thought to be on the path to recovery. Recent recreational and commercial landings of weakfish along the Atlantic Coast approached all-time lows as population estimates derived from age structured (de Silva 2002; Kahn 2002a) or biomass dynamic models (Uphoff 2005a) reached all-time highs. This increasing dichotomy between weakfish stock assessment results and fishery performance has lead the Weakfish Technical Committee to re-examine the basic survey data used and to consider external factors that lie outside of the purview of traditional assessments. One of the recommendations of the 40$^{th}$ Stock Assessment Review Committee (or SARC) examination of our preliminary assessment was for the Weakfish Stock Assessment Subcommittee (WSAS) to formulate multiple hypotheses about stock status and evaluate them with empirical data, an approach advocated by Sainsbury (1998) as part of a new paradigm for stock assessment in the 21$^{st}$ century.

A great preponderance of evidence indicates that weakfish abundance and surplus production have declined to low levels (Crecco 2005a or b; Weakfish Stock Assessment Report Part 1 or Part 1). The most reliable estimates of trends or values of F during 1981-2003 have indicated it has been modest since at least 1995 (Part 1). This has lead to the formulation of a hypothesis that the most likely cause of declining weakfish fortune is increased natural mortality (Part 1).

We specifically addressed the hypothesis that M has been changing for weakfish and that it is the primary driver behind the recent crash. At this stage, an increase in M in recent years is a default postulate reflecting the difficulty in finding evidence of increasing F other than by adhering dogmatically to the notion that M is constant for weakfish at 0.25. We investigated hypotheses that weakfish biomass dynamics, growth, and survival were negatively affected by striped bass competition and predation exacerbated by depleted forage (hereafter, predation hypothesis). In particular, this is an alternative, nonfishing mortality hypothesis explaining an aborted weakfish recovery. We conducted an analysis on a portion of the food web (weakfish, its primary fish competitor, and three forage fish species) along the mid-Atlantic region (New York-North Carolina) that constitutes the "core area" for weakfish stock assessment (Northeast Fisheries Science Center 2000). We also addressed the potential for other candidate predator-competitors to contribute to the recent decline of weakfish.

We undertook statistical explorations of the inter-relationship of weakfish, striped bass (weakfish's primary competitor and potential predator), four other potential predator-competitors (summer flounder, bluefish, spiny dogfish, and Atlantic croaker), two main forage species for piscivores along the mid-Atlantic (bay anchovy and Atlantic menhaden) and a forage species of demonstrated importance within Chesapeake Bay but possibly more limited importance elsewhere (spot; Mercer 1985; Taylor 1987; Hartman and Brandt 1995; Hartman 2003; Walter et al. 2003). Weakfish have been specifically identified as a minor food item in some, but not all, striped bass diet studies in the mid-Atlantic region (Manooch 1973; Austin and Walter 1998). In the mid-Atlantic region, bay anchovy represent the prey most consumed by these species as they initiate piscivory, but both predators switch predominately to similar, larger prey (clupeids, primarily Atlantic menhaden) within a year (Mercer 1985; Taylor 1987; Hartman and Brandt

1995). Juvenile menhaden and spot are most relevant to younger, smaller weakfish making the transition through piscivory because piscivorous fishes are size selective and gape limited, and typically select prey that are 20-30% of their length (Stein et al. 1988; Juanes 1994). Stakeholders, Weakfish Management Board members, and other biologists have suggested that Atlantic croaker, summer flounder, bluefish, and spiny dogfish may be potential predator-competitor candidates for explaining the decline in weakfish. Each of these species inhabits mid- and north Atlantic waters where concerns about the depletion of weakfish are greatest.

Weakfish and striped bass make an early switch to a fish diet (age 0 for weakfish and age 1 for striped bass; Mercer 1985; Hartman and Brandt 1995; Hartman 2003; Walter et al. 2003). This early switch to a fish diet indicates that both species are specialized piscivores (Persson and Bronmark 2002). Early switching requires high growth rate, which implies high densities of proper forage and safe foraging opportunities. If unfavorable conditions prevail, growth is reduced, and vulnerability to competitors and predators is increased. Population densities of specialists are generally a result of their success in a feeding stage where they experience intense competition (Persson and Bronmark 2002). Species undergoing ontogenetic diet shifts face a risk of delayed transitions among feeding stages if food resources are limited and competition is intense. Such ontogenetic bottlenecks are common in piscivorous fishes because competition may retard growth and prevent size advantage necessary to feed on the larger prey in the next stage. Individuals not reaching size advantage over prey may become stunted at size where consumption balances metabolic requirements (Bax 1998; Persson and Bronmark 2002).

Empirical models can be used to detect potentially important patterns of fish predation and may provide insight into processes that may be responsible for patterns described in the analysis (Whipple et al. 2000). We explored whether shifts in weakfish landings growth, natural mortality, and distribution (or their proxies) coincided with forage abundance and striped bass biomass using correlation and regression analyses, inferring competition for forage if test results were logical and statistically significant. This approach provided a bridge between the common assumption that predation and competition imposes a constant rate of mortality allowing the stock to be assessed in isolation from its environment (single species assessment; Bax 1998; Sainsbury 1998) and the more complex process-based multispecies models (Whipple et al. 2000).

Abundances of many exploited fish stocks vary widely and these variations may not be explained with single species population models (Spencer 1997). There is increasing evidence that concurrent changes multiple stocks occur at longer time-scales (Steele 1996). Often environmental factors are sought as underlying causes for changes in status, but sustained periods of high and low abundance are often exhibited by fish populations that are much more dramatic than shifts in climate or other environmental factors (Steele and Henderson 1984). These shifts can be regarded as jumps between alternative equilibrium states of ecological systems (Steele and Henderson 1984). The term “regime shift” has been used to suggest these changes are causally connected and can be linked to other changes in an ecosystem (Steele 1996). There is an assumption that environmental factors are the underlying mechanism with fishing as a contributing element (Steele 1996). Continuous changes in intrinsic population growth rate, carrying capacity, F, or rate of predation can lead to “flips” into periods of high or low abundance (Spencer and Collie 1995). A classical logistic population growth formula

combined with an S-shaped predation function reproduces these fluctuations when subjected to simulated directional environmental fluctuations or changes in fishing pressure (Steele and Henderson 1984; Collie and Spencer 1993; Spencer and Collie 1997a).

We applied the predator-prey model of Steele and Henderson (1984) to examine relative effects of fishing and striped bass predation and competition on recent (1981-2003) weakfish dynamics. We interpreted the "effect" of striped bass to potentially include collateral damage to weakfish such as starvation and cannibalism due to competition, as well as direct consumption by striped bass.

When applied generally, this predator-prey model has reproduced the types of rapid shifts in abundance exhibited by marine populations and it was useful in exploring the role of dogfish predation on Georges Bank haddock recovery and management (Spencer and Collie 1995; 1997b). This predator-prey model is essentially a Schaefer biomass dynamic model with a sigmoidal type III predation function added to estimate additional predation losses (Collie and Spencer 1993). In this analysis, it provided estimates of M and F that quantified the extent that striped bass, other candidate predator-competitors species, and fishing mortality could be influencing weakfish.

## METHODS

### Data Sources for Statistical Analyses for Forage and Striped Bass Influences with Indices and Landings as Stock Size Indicators

Commercial landings (1950-2003) of striped bass and weakfish were obtained from the National Marine Fisheries Service's website (www.st.nmfs.gov/st1/). These data (Figure 1) represented the longest time-series readily available for both species that could be used to look for changes on decadal time-scales.

We used weakfish recreational catch rates (private/rental harvest and releases per trip in mid-Atlantic state waters based on all trips) as an indicator of stock biomass (Crecco 2006). Recreational catch per effort indices (WRI) were available for 1981-2003. Weakfish 25 cm FL and larger weakfish have constituted the bulk of weakfish measured by the MRFSS. Brust (2004) determine a MRFSS directed trip index of weakfish catch (harvest and releases) per trip when effort was limited to weakfish plus a suite of five species (summer flounder, Atlantic croaker, spot, bluefish, and black sea bass) considered to be commonly associated with weakfish. This index was very closely correlated (Pearson $r = 0.96$, $P < 0.0001$) with the more general WRI (Crecco 2005b), so it was not considered further in analyses.

Delaware and New Jersey trawl survey exploitable biomass indices (Z-transformed with one added for plots; Uphoff 2005a; Part 1) were used as additional indicators of weakfish stock biomass. Larger sizes of weakfish present in WRI were present in these surveys (Uphoff 2004). A third trawl survey, the Northeast Fisheries Science Center fall survey was not considered because exploitable-sized weakfish were not well represented (Uphoff 2004) and because of concerns about high inter-annual variability expressed by reviewers at the 40$^{th}$ SARC.

We examined whether catchability (q) of WRI, DE, and NJ indices was proportional to stock biomass. Each annual biomass index was divided by converged VPA biomass estimates (1982-1993 were considered converged) to estimate q. These estimates of q were plotted against converged biomass. Correlation analysis was used to describe associations of WRI, and DE and NJ trawl indices.

Weakfish weight at age data consisted of estimates for 1982-2003 from the VPA catch-at-age matrix. Trends in ages 1-5 were examined; older ages aggregated into an age 6+ group were not used because of possible bias from different age compositions. Scale ages had been converted to otolith ages for the early half of the matrix (NEFSC 1998).

We used the quality+ proportional stock density index (DE PSD Q+) derived from the Delaware trawl survey to summarize long-term 1966-2003 length-frequency data (Uphoff 2004; Part 1). The Delaware trawl survey time-series was not continuous (1966-1971, 1979-1984, and 1990-2003). The Delaware Quality+ PSD (DE PSD Q+) equaled the proportion of weakfish greater than or equal to 210 mm that were 340 mm or larger. The DE PSD Q+ index was significantly and positively associated with recreational fishing quality (trophy citations) over a broad area (DE, MD, and VA), commercial and recreational yield along the Atlantic Coast, WRI, and the proportion of recreational harvest outside of 3 miles (Uphoff 2004; Part 1).

The annual sum of ADAPT VPA biomass estimates for 2 year-old and older striped bass were used as competitor biomass during 1982-2003 (A. Sharov, MDDNR, personal communication; Uphoff 2003). The average of age 2+ striped bass biomass estimates for 1982-1986 was used as an estimate for 1981 (6,236 mt). Atlantic menhaden dominated diets of striped bass age 2 and greater in the early 1990s in upper Chesapeake Bay (Hartman and Brandt 1995) and were one of the dominant food items along the Atlantic coast (Walter et al. 2003; Nelson et al. 2003). Striped bass of this size would also be important predators of spot (Hartman and Brandt 1995) and would be capable of consuming weakfish.

Striped bass egg-presence absence in Chesapeake Bay spawning rivers (proportion of plankton tows with striped bass eggs; hereafter the large bass biomass index or LBI) was used as a long-term index of biomass (1955-2003; Uphoff 1997). Egg presence-absence scaled relative biomass between 0 and 1. This index tracks biomass of mature spawning females, generally bass 6 years-old or older, but was assumed to be a general indicator of stock biomass.

Indices of Atlantic menhaden, spot, and bay anchovy relative abundance were obtained from agencies in NC, VA, MD, DE, and NJ. Survey locations, gears, time-series duration, estimator of central tendency reported, data source, and which of the three forage species was surveyed were summarized in Table 1. In one case (Atlantic menhaden in Ablemarle Sound), two estimators of central tendency were used. All forage indices were z-transformed to place them on the same scale and split into two regions (NC-MD or DE and NJ) for graphic presentation.

Age 0 abundance estimates of Atlantic menhaden along the Atlantic Coast were available for 1955-2002 (ASMFC 2004a). A long-term juvenile menhaden time-series (1959-2003 proportion of seine hauls in Maryland's portion of Chesapeake Bay; Table 1; Uphoff 2003) was substituted for age 0 abundance estimates in some analyses. The menhaden juvenile index and juvenile abundance estimates are significantly related ($r^2 = 0.67$, $P < 0.001$), but the MD index indicated substantially higher relative abundance of juveniles in the 1970s and 1980s than the abundance estimates. Coastal abundance estimates of our other forage species did not exist, so we could not determine whether they might be applied broadly as we did with the MD juvenile menhaden index.

Statistical Analyses for Forage and Striped Bass Influences with Indices and Landings as Stock Size Indicators

Statistical analyses featured either weakfish commercial landings (1950-2003), DE PSD Q+ (1966-2003, discontinuous time-series), DE and NJ trawl survey indices, or WRI (1981-2003) as dependent variables. Estimates of absolute stock size based on single species stock assessment models were not used for statistical analysis because assumptions of constant natural mortality (VPA) and ecological stability (biomass dynamic models) were necessary to derive these estimates (Mertz and Meyers 1997; Spencer and Collie 1997b). Scatter plots of all bivariate analyses were examined for linear or nonlinear associations or relationships. Ecological systems are highly nonlinear and it was likely that the dynamics of interest might not be reasonably approximated as linear functions (Sainsbury 1998). Functional responses of predators are often nonlinear and time lags in the response of predators to prey and vice versa would be likely (Bax 1998). Natural log transformations were used to induce linearity in some cases.

Correlation analysis was used to empirically explore associations. Level of significance was adjusted for multiple comparisons by dividing $P = 0.10$ by the number of comparisons made for each species. Regressions and correlations were considered significant at $P \leq 0.10$. Residuals were examined for normality and serial trends.

Weakfish landings were plotted against striped bass landings, with each decade (starting in 1950) illustrated by a different symbol; landings from 2000-2003 were included with the 1990s. This differentiation of decades allowed examination of whether the 1970s and 1980s had a different or shifted relationship than the remaining decades. This plot allowed for development of an analytical strategy for examining the hypotheses that (1) striped bass and weakfish landings were negatively related and (2) a shift over decadal time scales was present in the landings data.

We used categorical regression to evaluate these hypotheses. The different decadal groups were coded as 0 (low period; 1960-1969 and 1990-2003) and 1 (high period; 1970-1989) and used with landings as independent variables in a multiple regression (Neter and Wasserman 1974). This test assumed that the slopes of the weakfish and striped bass landings were equal, but intercepts (decades) were different (Neter and Wasserman 1974).

Stepwise multiple regression analysis was used to test the relationship of ln-transformed weakfish landings to ln-transformed menhaden abundance or the Maryland juvenile menhaden

index and LBI. Partial correlation coefficients were calculated to judge the contribution of each variable to model fit (Ott 1997).

We used correlation analysis to explore associations of DE PSD Q+ and available forage fish (Atlantic menhaden, spot, and bay anchovy) relative abundance indices along the mid-Atlantic. The long-term association (1966-2003) of weakfish size quality and striped bass biomass was examined by correlating weakfish DE PSD Q+ and LBI. The short-term (1982-2003) association of weakfish DE PSD Q+ and age 2+ striped bass biomass was also explored with correlation analysis. We developed a multiple regression model of DE PSD Q+ against LBI and Atlantic Coast age 0 menhaden abundance to test the hypothesis that both this predator/competitor and important forage species influenced the size dynamics of weakfish during 1966-2002. In general, forage species were expected to have positive associations or relationships with weakfish DE PSD Q+ and striped bass were expected to have been negatively associated or related.

Weakfish abundance along the Atlantic Coast during 1981-2003, indexed by WRI or the standardized (z-transformation) DE and NJ trawl surveys, were plotted against age 2+ striped bass biomass. Statistical descriptions of these data were not attempted after viewing the complex relationships exhibited in the plots.

Time Varying Natural Mortality from VPA

Standard output from the ADAPT VPA includes biomass weighted fishing mortality rates of ages 1+ weakfish ($F_{vpa}$) from 1982 to 2003 (Part 1; Crecco 2006; 2005a). As a result, biomass weighted total mortality ($Z_{vpa}$) rates from 1982 to 2003 were easily derived by adding 0.25 to each of the aggregated $F_{vpa}$ values from VPA run 20 (MRFSS recreational CPUE as the sole tuning index). The WSAS chose run 20 as the preferred VPA model run. The degree of retrospective bias in recent $F_{vpa}$ and weakfish stock size estimates from run 20 was much less extensive that the bias for other model runs that were tuned by either trawl survey indices alone, or a combination of trawl survey and MRFSS indices (D. Kahn, DEDFW, personal communication). Note that rescaled F analysis (Crecco 2005a) estimated biomass weighted F of the same ages encompassed in $Z_{vpa}$, but independently from the VPA (Crecco 2006). As a result, a time-series of biomass weighted natural mortality rates ($M_{vpa}$) of ages 1+ weakfish were calculated for each year t from 1982 to 2003 by

$$(5)\quad M_{vpat} = Z_{vpat} - F_{RFAt};$$

where $F_{RFAt}$ is the rescaled F estimate and $Z_{vpat}$ total mortality estimate based on VPA run 20.

Striped Bass-Weakfish Predator-Prey Modeling

WRI during 1981-2003 was used as an index of relative abundance for analyses with the Steele and Henderson (1984) model (Table 2). Landings during 1981-2003 included both directed harvest and discards by the recreational and commercial fisheries (Crecco 2005; Part 1). Biomass estimates for 2 year-old and older striped bass were used as predator-competitor biomass during 1981-2003 (Table 2).

We used a spreadsheet version of a Schaefer (logistic) biomass dynamic model formulated by Haddon (2001) and added the type III predation function to it (Steele and Henderson 1984; Collie and Spencer 1993; Spencer and Collie 1995). The predator-prey model used the following discrete time-step equation:

$$(6)\ B_t = B_{t-1} + rB_{t-1}\ (1-(B_{t-1} / K)) - H_{t-1} - [(cP_{t-1}(B_{t-1})^2)/(A^2+(B_{t-1})^2)] + \varepsilon;$$

where $B_t$ was weakfish biomass in year t; $B_{t-1}$ = biomass the previous year, r = intrinsic rate of population increase; K = maximum population biomass; $H_{t-1}$ = harvest (commercial and recreational, including discard estimates) in the previous year; maximum c is per capita consumption by predator (striped bass) biomass ($P_{t-1}$); A is weakfish biomass where predator satiation begins; and ε is measurement error (Hilborn and Walters 1992: Collie and Spencer 1993; Spencer and Collie 1995). The Haddon (2001) spreadsheet version of the logistic model was easy to adapt to this predator-prey formulation because it estimated weakfish biomass as a first step and then estimated catchability (q) as $B_t/WRI_t$ (Haddon 2001). Estimating weakfish biomass first allowed striped bass biomass to be used directly and parameter A to be estimated directly rather than converting them to weakfish index equivalents. The mean of the estimates of $q_t$ ($q_{mean}$) was used to predict $WRI_t$ as $B_t * q_{mean}$. Biomass was estimated directly for 1981 ($B_{1981}$) and then the model estimated subsequent years (Haddon 2001).

Standard Schaefer model equilibrium biological reference points (BRPs), $F_{msy}$ (r/2) and $B_{msy}$ (K/2) were estimated (Haddon 2001). In providing guidance on precautionary approach BRPs to the National Marine Fisheries Service, Restrepo et al. (1998) recommended $F_{msy}$ and $B_{msy}$ as limit reference points. $F_{msy}$ constituted the threshold over which overfishing was occurring and $B_{msy}$ determined the stock size below which the stock would be considered overfished (Restrepo et al. 1998). BRPs adopted for weakfish management under Amendment 4 (ASMFC 2002) were $F_{30\%}$ as a target F (0.31), $F_{20\%}$ (0.5) as a limit BRP, and 20% SSB of unfished stock size (14,400 mt) as a threshold. These reference points were dependent on an age-structured stock assessment and could not be used in comparisons with production model-based BRPs, therefore $F_{msy}$ and $B_{msy}$ were substituted.

An observation error model was used that assumed all residual errors were in the index observations and the equation used to describe the time-series was deterministic and without error (Haddon 2001). A genetic algorithm super solver (Evolver, Palisade Corporation) was used to estimate predator-prey model parameters that minimized observation error (observed ln $WRI_t$ - predicted ln $WRI_t)^2$ (Haddon 2001). The spreadsheet version of the model combined with the genetic algorithm provided a great deal of flexibility for trying different model variations. Residuals were examined to see if they were normally distributed with a mean of zero and to see if serial trends were present.

Instantaneous annual fishing mortality rate in year t was estimated as:

$$(7)\ F_t = H_{t-1} / [(B_t + B_{t-1}) / 2] \text{ (Ricker 1975).}$$

An equivalent instantaneous natural mortality rate associated with striped bass predation and competition was estimated. The type III predator-prey term in equation 1:

$$(8)\ \ [(cP_{t-1}(B_{t-1})^2)/(A^2+(B_{t-1})^2)]\ ,$$

estimated loss of weakfish biomass, $D_t$, that was equivalent to catch $H_t$. Instantaneous annual natural mortality associated with striped bass was estimated as:

$$(9)\ \ M_{bt} = D_{t-1} / [(B_t + B_{t-1}) / 2].$$

Total instantaneous annual mortality of weakfish ($Z_{bt}$) due to due to fishing and striped bass predation equaled $F_t + M_{bt}$. This estimate did not account for other sources of natural mortality not associated with food web effects represented by striped bass.

Consumption of weakfish biomass per unit of striped bass biomass was estimated as

$$(10)\ \ D_t / P_t.$$

The functional response of striped bass to weakfish was displayed visually by plotting $D_t / P_t$ against $B_t$.

Surplus production estimated from the logistic predator-prey analysis ($SP_t$) was estimated with two equations. The first estimate was from the standard equation.

$$(11)\ \ B_t - B_{t-1} + H_{t-1}$$ (Prager 1994; Jacobson et al. 2002).

The second estimate of SPt explicitly accounted for losses due to striped bass predation and competition:

$$(12)\ \ B_t - B_{t-1} - D_{t-1} + H_{t-1}.$$

Surplus production estimated by both equations was plotted against F and $M_b$ to explore the possible linkage of these two sources of mortality to changes in surplus production.

Estimates of F or Z from the predator-prey model were compared to $F_{Rfa}$ (F from rescaled relative F analysis; Crecco 2005a; 2006), estimates of F from a Schaefer biomass dynamic model without a predator-prey term (based on WRI), or $Z_{vpat}$. Biomass estimates were compared among predator-prey, Schaefer (described below), and rescaled relative F models. Weakfish exploitable biomass estimated by the predator prey model was plotted with age 2+ striped bass biomass and combined weakfish and striped bass biomass.

Bootstrapping (Efron and Gong 1983) was used to describe variability of parameters estimated in the spreadsheet version of the logistic predator-prey model. The bootstrapping technique recommended by Prager (1994) that preserved the original order of the time-series was used. For each set of bootstrap trials, a synthetic data set was constructed by combining a random sample of the original residuals with the ordered predictions from the original fit; the model was then rerun with each set of synthetic observations (Efron and Gong 1983; Prager 1994; Haddon

2001). Percentile confidence intervals of model parameters (r, K, $B_{1981}$, c, and A) and the time-series of biomass, F, and $M_b$ were estimated.

Several approaches were used to investigate sensitivity of predator-prey model parameters (r, K, $B_{1981}$, c, and A) and estimates of F, $M_b$, and biomass. All sensitivity analyses were deterministic; bootstrapping was not used. We were particularly attuned to changes that created a decline in biomass at the end of the time-series such as that exhibited in the rescaled relative F analysis (Crecco 2005). Results (SSQ, $r^2$, residuals, estimates of parameters r and K, and F and biomass time-series) from the S-H striped bass-weakfish model were contrasted with a Schaefer biomass dynamic model using the WRI. Sensitivity of model parameters to the beginning or ending of the time-series was tested by removing up to three years of data and running the model. An additional sensitivity run used a fixed value for $B_{1981}$ , 49,000 mt, predicted from a regression of DE PSD Q+ and average biomass estimated from rescaled F analysis.

Alternative Weakfish Predator-Competitors

Three approaches were used to evaluate the potential of Atlantic croaker, bluefish, summer flounder, and spiny dogfish to influence weakfish biomass dynamics. First, long-term trends in Atlantic Coast commercial landings were analyzed for trends to determine if negative associations with weakfish landing were suggested any of the candidate species. We assumed that landings would be largely reflective of stock biomass in this long-term analysis. Second, biomass estimates from single species assessments, generally within 1981-2003, were obtained and used as predator biomass ($P_{t-1}$ in equation 6) in a species-specific predator-weakfish model used above to explore weakfish-striped bass biomass dynamics (see *Predator-Prey Modeling*). Analytical results were contrasted with those found for striped bass. Finally, literature on candidate species' diets was reviewed to see if predation on weakfish and competition for bay anchovy, Atlantic menhaden, and spot were possible.

Commercial landings (1950-2003) of the four candidates were obtained from the National Marine Fisheries Service's website (www.st.nmfs.gov/st1/; Figure 1). Some bias was likely introduced by increasingly restrictive management after the early 1980s for most of these species (Atlantic croaker would possibly be a lightly regulated exception). After inspection of trends, landings of dogfish were dropped from the analysis. Dogfish landings (not separated by species) were generally low throughout the time-series, but were punctuated by several year periods of high landings. These rapid changes did not appear in character with an animal with modest reproductive characteristics (slow growth, delayed maturity, long gestation, and small number of pups produced; NEFSC 2003). Correlation analysis was used to determine associations ($P \leq 0.10$) among candidate species' landings and weakfish landings. A significant, negative correlation with weakfish would suggest that a candidate species was a predator-competitor.

Biomass time-series from single species assessments were obtained for Atlantic croaker (ASMFC 2005), bluefish (NEFSC 2005a), summer flounder (NEFSC 2005b), and spiny dogfish (NEFSC 2003). Species, time-series and estimation technique were as follows: age 1+ Atlantic croaker SSB, 1981-2002, age structured surplus production model; age 1+ bluefish biomass, 1982-2003, VPA; age 1+ summer flounder biomass, 1982-2003, VPA; and total biomass of spiny dogfish, 1981-2003, expanded area swept by survey trawl (Lowess smoothed). Atlantic

croaker SSB was considered a reasonable proxy for biomass since 90% were considered mature at age 1 and all were mature afterward (ASMFC 2005).

We applied the logistic predator-prey model to examine relative effects of fishing and potential predation and competition from each of our four candidate species on recent (1981-2003) weakfish dynamics. The application of this model for weakfish and striped bass was described in detail above. Deterministic runs were made; bootstrapping and sensitivity analyses were not explored. Model fit ($r^2$ of observed and predicted indices), its ability to produce a decline in weakfish biomass after the late 1990s, and how closely its levels of weakfish biomass were to those estimated by Crecco (2005) were used to evaluate each candidate predator-competitor. Weakfish biomass estimates of Crecco (2005a) were termed "observed" quantities in these comparisons.

A "scorecard" was kept for each candidate species. Ten criteria were considered - four based on statistical or model results, and six on surveyed diet literature (Table 3). Each variable could be scored between 0 and 1. Maximum score summed to ten. Eight variables were dichotomous, while two were continuous. All six literature variables on diet presence were dichotomous: presence of weakfish, bay anchovy, Atlantic menhaden, spot, clupeids, and sciaenid. In order for a score of one to have been considered in the clupeid and sciaenid categories, diet summaries had to either consider these general categories only or species other than weakfish, menhaden or spot had to be identified. The regression coefficient between the biomass estimates made for 1981-2003 by rescaled F analysis and predator-prey analysis was one of the continuous scores and the biomass closeness ratio of mean 1981-2003 biomass made by rescaled F and predator-prey analyses was the other. This latter ratio was expressed to keep it less than one (either rescaled F biomass to predator-prey biomass or vice-versa) depending on species-specific bias (Table 3).

## RESULTS

Statistical Analyses for Forage and Striped Bass Influences with Indices and Landings

Recreational catch per trip (WRI) was intermittently high during 1981-1988, fell to a low level through 1993, rose to a peak similar to previous highs by 1996 and then fell steadily to its nadir in 2003 (Figure 2). Delaware biomass indices were consistently low during 1981-1984. Both the NJ and DE biomass indices indicated a substantial rise during 1990-1996 and both fell afterwards, although the decline in DE was more substantial and consistent than NJ. All three indices had declined by 2003, but the magnitude of decline was inconsistent. WRI had approached its lowest level ever, DE was quite low but not at its lowest, and NJ was somewhat low but had been fluctuating annually between low and high for five years (Figure 2).

Estimated q of the WRI varied over the time-series (CV = 36%), but was generally stable across the estimates of converged VPA biomass (Figure 3). The highest estimate was about three-times greater than the lowest. The two highest estimates of WRI q occurred earliest in the time-series (1981 and 1982) at a mid-level of biomass (≈ 20,000 mt). Scatter plots of DE and NJ biomass indices suggested inverse relationships of q and biomass at worst and random 10-fold fluctuations at best. Highest estimates of q in both state surveys occurred at the lowest biomass (Figure 3). Coefficients of variation of these two surveys' catchability estimates during 1982-

1993 were near 100%. We considered these trawl surveys qualitative indicators of changes in biomass.

Correlation of WRI and DE biomass index was not significant when 1981-1984 were included. All three sets of indices were positively correlated with each other during 1989-2003 (WRI and DE, Pearson $r = 0.90$; WRI and NJ, Pearson $r = 0.71$; DE and NJ, Pearson $r = 0.79$; $P \leq 0.003$ in all cases).

Mean weight-at-age was higher prior to 1993 and the difference between mean weights-at-age during 1981-1992 and 1993-2003 increased with age (Figure 4). Median average weight-at-age during 1982-1992 was 7% larger than during 1993-2003 for age 1, 22% larger for age 2, 34% for age 3, 80% for age 4, and 85% for age 5.

The DE PSD Q+ index indicated that size quality of weakfish in recent years was quite poor (Figure 5). A recovery in size quality in the 1990s faltered after 1998; the percentage of quality sized and larger weakfish fell from about 20% in 1998 to 1% in 2003. Weakfish DE PSD Q+ has the potential to be a good bit higher than the peak observed in 1998. Values in the early 1980s were twice as high (45%) as the peak observed in 1998 (Figure 5).

Biomass estimates of age 2+ striped bass were low (5,500-7,700 mt) during 1982-1986 (Figure 6). Biomass rose steadily from 12,000 mt to 83,000 mt during 1987-1998 and then rose slowly to 104,000 mt by 2003. *LBI* was near 0.80-0.90 during 1966-1978 with a hiatus near 0.65 during 1971-1974. After 1978, *LBI* steadily fell and reached a low of about 0.35 during 1983-1984. *LBI* rose rapidly after 1985 and reached 0.80 in 1992; *LBI* has fluctuated near 0.80 during 1993-2003. Age 2+ biomass was positively and significantly correlated with *LBI* (Pearson $r = 0.71$, $P < 0.0002$). Striped bass recovery indicated by *LBI* was much more rapid than VPA estimates of age 2+ biomass, but the relative scale of recovery was similar (Figure 6).

Striped bass biomass was negatively associated with weakfish size quality. Weakfish DE PSD Q+ was significantly and negatively correlated with ln-transformed striped bass age 2+ biomass during 1982-2003 (Pearson $r = -0.74$, $P = 0.0007$) and with *LBI* during 1966-2003 (Pearson $r = -0.67$, $P = 0.0002$).

Indices of relative abundance of Atlantic menhaden in MD, VA, and NC exhibited similar trends (Figure 7). Abundance was low during 1966-1970 and after the early 1990s. Abundance was slightly to well above the time-series average during 1974-1986. Relative abundance was slightly below average during 1987-1991 and then decreased to previous lows observed during 1966-1970 (Figure 7). Relative abundance of menhaden in Delaware Bay surveys (DE and NJ) was steady and low prior to 1993 and has fluctuated from slightly below average to well above the time-series average in the past decade (Figure 8). Coastal abundance estimates of age 0 Atlantic menhaden ranged from 128 to 850 $\bullet 10^9$ (Figure 9). Age 0 abundance estimates were frequently in the lowest quartile ($< 280 \bullet 10^9$) during 1966-1972 and after 1994 and frequently in the upper quartile ($> 569 \bullet 10^9$) during 1975-1991. These age 0 population estimates exhibited a pattern similar to that observed in Chesapeake Bay and Ablemarle Sound surveys, but dissimilar to Delaware Bay.

Trends in spot relative abundance in MD and VA were similar to those of Atlantic menhaden; abundance was low during 1966-1971 and after 1991, and high in the interim (Figure 10). Relative abundance in MD and VA appeared to have been suppressed since the mid-1990s, while Pamlico Sound exhibited similar fluctuations as those observed in the early half of its time-series (Figure 10). Indices in Delaware Bay (DE and NJ) exhibited large fluctuations of high to low during the 1980s and early 1990s (Figure 11). These fluctuations began to dampen in the mid-1990s and indices have been below the time-series average since 1998 (Figure 11).

Bay anchovy indices in MD and VA fluctuated about their time-series means during 1966-1986 (Figure 12). An index was not available for NC. After 1994, MD Chesapeake Bay and MD coastal bay indices became asymptotic at a below average level, and VA indices were typically, but not always, below average (Figure 12). Bay anchovy indices in DE and NJ fluctuated above and below their means throughout their time-series (Figure 13).

Significant ($P < 0.10$) positive associations of DE PSD Q+ and forage relative abundance occurred consistently (but not among all surveys) in MD and VA for all three species (Table 4). Significant positive correlations (Pearson $r = 0.60$-$0.79$) with DE PSD Q+ were exhibited for Atlantic menhaden in MD, VA, and NC indices (3 of 4 comparisons) and coastwide abundance estimates. Spot were significantly and positively associated (Pearson $r = 0.54$-$0.73$) with PSD Q+ in DE Bay (1 of 3 surveys), and both Chesapeake Bay seine surveys. The VA Chesapeake Bay trawl survey index was positively, but not significantly correlated. Bay anchovy were significantly associated with PSD Q+ in MD ocean bay trawl and VA Chesapeake Bay seine surveys (Pearson $r = 0.61$ and $0.63$, respectively). Two other Chesapeake Bay surveys of bay anchovy were not significantly correlated with PSD Q+, nor were surveys from other geographic locations (Table 4).

The multiple regression model of weakfish DE PSD Q+ versus *LBI* and age 0 menhaden abundance during 1966-2003 was significant ($r^2 = 0.61$, $P < 0.0001$). Partial regression coefficients indicated age 0 menhaden abundance ($P < 0.0001$) explained 50% of variation in weakfish PSD Q+ and striped bass biomass accounted for 11% ($P = 0.02$). The model picked up the general trend (rise and fall) of the DE PSD Q+ time-series, but did not always match the details (Figure 14).

The scatter plot of WRI and age 2+ striped biomass (Figure 15) exhibited at least four stanzas that were sequential with both striped bass biomass and time. During 1982-1988, striped bass biomass was below 20,000 mt and WRI was high on average, but also highly variable. During 1989-1993, striped bass biomass rose from 20,000 to 40,000 mt while WRI was steady and low. Both striped bass biomass and WRI rose steadily and then held steady during 1994-2000; striped bass biomass reached about 85,000 mt while WRI returned to high levels exhibited during the early 1980s. In the final stanza (2001-2003), striped bass biomass continued to increase past 100,000 mt, but WRI steadily decreased and reached its nadir (Figure 15).

The relationship of weakfish exploitable biomass, indicated by DE and NJ trawl survey indices and striped bass age 2+ biomass (Figure 16) was similar to that exhibited by WRI. The earliest data, DE trawl survey during 1982-1984 indicated much lower relative biomass than WRI. Trends in remaining data (1989-2003) were very similar to WRI. Exploitable biomass indices

increased from about 0.1 to 3.0-4.0 concurrently with striped bass increasing from 20,000 to 70,000 mt. As striped bass biomass continued to rise to 100,000 mt in 2003, weakfish biomass indices fell to 0.5-1.0. A consistent indication of decline was not evident until 2003 (Figure 16).

Examination of long-term commercial landings of weakfish and striped bass (1950-2003) suggested that periods of high weakfish landings corresponded to low periods of striped bass landings and vice-versa. Decadal differences were evident when weakfish landings were plotted against striped bass landings (Figure 17). Weakfish landings were shifted upwards during 1970-1989 at the same amount of striped bass landings as during remaining years. A negative relationship of striped bass and weakfish landings that reflected two periods of underlying weakfish productivity was described by the multiple regression of weakfish landings against period and striped bass landings (Figure 17). This regression was significant at $P < 0.001$ and explained 76% of variation in weakfish landings. The relationship was described by the equation $W = -0.47*B + 5720*C + 4115$; where W = weakfish landings; B = striped bass landings, and C = decadal category (low = 0 = 1950-1969 and 1990-2003; high = 1 = 1970-1980). The net visual effect of this regression was to depict predicted weakfish landings as abrupt decadal blocks, with slight declines in the low periods and a slight increase during the high period (Figure 18). All coefficients and the intercept were significantly different from zero. Residuals appeared normally distributed with a mean near zero (mean = $3 \bullet 10^{-13}$). When categories were ignored, relationship of striped bass to weakfish commercial landings was negative and significant, but weak ($r^2 = 0.12$); a pronounced serial trend corresponding to the high and low periods was evident in the residuals.

Multiple regression analysis suggested a negative, nonlinear relationship between weakfish landings striped bass biomass (indexed by LBI) and a positive, nonlinear relationship with $\log_e$-transformed juvenile Atlantic menhaden abundance (MJ) during 1955-2002. There was an overall significant negative correlation between LBI and $\log_e$ MJ (Pearson $r = -0.49$, $P < 0.0004$), but this correlation was not "close" enough to warrant elimination of either variable in the multiple regression (Ricker 1975). The model was significant ($R^2 = 0.52$, $P < 0.0001$) and was described by the equation:

$$\log_e W = -1.75*LBI + 0.53 * \log_e MJ - 4.41;$$

where W = weakfish landings, LBI = striped bass egg presence-absence index, and MJ = menhaden juvenile abundance. Partial $r^2$ indicated that $\log_e$ MJ explained 41% of variation ($P < 0.0001$) and LBI explained 11% ($P < 0.0023$). The model moderately overestimated weakfish landings during 1955-1960 and usually underestimated them (sometimes badly) during 1972-1982 (Figure 19). Landings were well predicted after 1985. Residuals were nearly always negative during 1955-1970, always positive during 1971-1982, and then alternated with 3-4 year periods of negative and then positive residuals. The mean of the residuals was very close to zero.

Stepwise regression of the Maryland juvenile menhaden index (MI) and LBI indicated both terms were significant ($R^2 = 0.76$, $P < 0.0001$; Figure 19); MI accounted for the vast majority of the fit (partial $r^2 = 0.73$, $P < 0.0001$) while striped bass accounted for a minor, but significant, fraction (partial $r^2 = 0.03$, $P < 0.04$). As above, there was an overall significant negative correlation between LBI and MI (Pearson $r = -0.52$, $P < 0.0002$), but this correlation was not

"close" enough to warrant elimination of either variable in the multiple regression (Ricker 1975). Residuals appeared normally distributed with a mean near 0; a serial trend was not evident. This regression model reasonably reproduced the time blocks of weakfish landings featured in the categorical regression expressed above; both predictions were significantly correlated (Pearson r = 0.81, $P < 0.001$).

Time Varying Natural Mortality from VPA

Although natural mortality of age 1+ weakfish was assumed to be constant in previous assessments (NEFSC 1998; 2000), the trend in annual biomass weighted natural mortality ($M_{vpa}$) from 1982 to 2003 does not support this assumption (Figure 20). $M_{vpa}$ estimates, though variable, changed systematically. A quadratic function (inverse parabola) fit the time trend of $M_{vpa}$ (all terms significant at $P < 0.00013$; $R^2 = 0.63$, $P < 0.0001$; Figure 20) and depicted $M_{vpa}$ falling from 0.75 in 1982 to near 0.25 during 1990-1993, then rising to 0.95 by 2003. The 1982-2003 average $M_{vpa}$ (mean $M_{vpa} = 0.47$, SE = 0.06) was significantly higher (t-statistic = 3.67, $P <0.01$) than the assumed constant M of 0.25 (Crecco 2006).

Predator-Prey Modeling

The Steele and Henderson (1984) predator-prey model fit the data well and explained 78% of the variation in the weakfish index (Figure 21). The model generally overestimated the index somewhat during 1989-1994 and underestimated it during 1996-2000 (Figure 21). Residuals had a mean of –0.052 and were skewed towards negative values. Model parameters were estimated as r = 1.17, K = 49,080 mt, c = 0.076, and A = 1,959 mt. Maximum sustained yield reference points were $F_{msy} = 0.58$ and $B_{msy} = 24{,}540$ mt.

The initial biomass estimate (1981) equaled 65,274 mt and exceeded the estimate of K (Figure 22). $B_{msy}$ was never exceeded after 1981. Biomass was about 19,000 mt in 1982 and fell to 7,900 mt by 1990; biomass rose to 16,000 mt in 1997 and then began to decline again, reaching 8,000 mt in 2003 and 5,700 mt in 2004 (Figure 22). Biomass estimates in 2003 and 2004 represented 40% and 32%, respectively, of $B_{msy}$ (or 20% and 16% of unfished biomass) under this set of ecosystem conditions.

Instantaneous annual fishing mortality rates rose from 0.5 to 1.3 during 1981-1988, fell to 0.4 by 1993, and then remained steady below $F_{msy}$ at about 0.4-0.5 during the following decade (Figure 22). Instantaneous annual natural mortality rates associated with striped bass were very low during 1981-1986 ($M_b < 0.04$) Estimates of $M_b$ rose steadily after 1986, equaled F by 1999-2000 ($M_b \approx 0.5$), exceeded F by 50% by 2002 ($M_b \approx 0.7$), and easily doubled F by 2003 ($M_b \approx 1.1$; Figure 22). Changes in biomass in the of the time-series largely reflected F until the late 1990s, when a decline largely reflected $M_b$. The large drop in biomass between 1981 and 1982 was not explained by either F or $M_b$.

Surplus production estimates ($SP_t$), calculated with or without accounting for striped bass competition, were near 12,000 mt during 1982-1986 (Figure 23). Estimates from both equations then began to fall through 1990. When striped bass losses were not included in estimation, $SP_t$

rose after 1990, peaked at about 7,400 mt in 1995, and then underwent a steady decline to about 400 mt by 2003. When striped bass associated losses were included in the estimation of $SP_t$ it declined slowly to 3,500 mt in 1992, remained steady there for three years, rapidly declined to near zero by 1998, and became increasingly negative afterwards (Figure 23).

Plots of $SP_t$ (estimated by either equation) against F (Figure 24) or $M_b$ (Figure 25) indicated a strong logical and negative influence of $M_b$, but not F; 1981 was omitted from the plots and appeared to represent an outlier. The plot of F versus $SP_t$ estimated by either equation indicated an illogical, positive association.

A low number of bootstrap trials were performed (N=50) after determining that precision of all estimated parameters was extremely high. Coefficients of variation (CV) of r, K, s, $B_{1981}$, c, and A were all below 1%. CV's of annual biomass, F, and $M_b$ were below 1% for 1981-2000 and would rise to 4-5% at the end of the time-series (biomass estimates were made through 2004; F and $M_b$ were estimated through 2003).

A Schaefer production model could not reproduce the recent decline in WRI without addition of a striped bass predation term (Figure 26). Sum of squares fell from 3.49 (Schaefer) to 2.62 (Steele and Henderson) with the addition of striped bass as a predator-competitor, primarily due to improved fit at the end of the time-series (2003 squared residual = 1.33 in the Schaefer model and 0.10 in the Steele and Henderson model). Improvement in overall fit was modest ($r^2 = 0.72$ without and 0.78 with predation term). Mean of the Schaefer model residuals was -0.075. Schaefer model residuals exhibited much of the same serial pattern described above for the Steele and Henderson model, but became sharply negative at the end of the time-series. Intrinsic rate of increase was estimated to have been much lower, 0.47, in the Schaefer model and K was considerably higher, 71,000 mt.

The time-series modeled had great bearing on the nature of the predator-prey relationship (c and A), but little influence on production parameters (r and K; Table 5) and equilibrium MSY reference points derived from them. Parameters r and K varied by no more than ±10% from the original fit (1981-2003) with the seven treatments. Predator-prey parameter c varied only 10% from the original estimate when years were removed from the end of the time-series, but changes were substantial (105-267%) when years were removed from the beginning. Parameter A was extremely sensitive to the time-series used. The original series produced the lowest estimate and other years' estimates were 370-1300% greater (Table 5).

Only models fit to the 1981-2003 or 1982-2003 time-series could reproduce the recent decline of the observed WRI out of the seven sensitivity treatments (up to three years removed from beginning or end of time-series and 1981 fixed at 49,000 mt; Figure 27). The remaining treatments indicated that biomass leveled-off or was rising slightly at the end of the time-series (Figure 27). The 2003 estimate of WRI influenced trajectory the most at the end of the time-series. Only the 1981-2003 and 1982-2003 time-series will be described further because of the inability of the other treatments to create a decline at the end of the time-series.

If the time-series began in 1981, modeled striped bass functional response was highly depensatory in the Steele-Henderson model; weakfish per bass was nearly constant (≈ 0.71-0.76)

across the entire range of estimated biomass (6,700-66,000 mt; Figure 28). The asymptotic value of weakfish biomass where striped bass demand for weakfish was satiated (A=1,959 mt) was greatly exceeded throughout the time-series. If 1982 was used to initiate the time-series, weakfish consumption per striped bass was much more density-dependent (changing nearly linearly from about 0.04 to 0.11 as weakfish biomass rose from 7,900 to 19,000 mt (Figure 28). Weakfish biomass at satiation (A=11,387) was reached within the time-series.

Trends in estimates of F were generally comparable among the predator-prey, rescaled relative F, and the Schaefer biomass dynamic models except during the more recent years (Figure 29). Fishing mortality was highest and generally increasing during the 1980s; F fell substantially during the early 1990s, and remained steady and low during the remainder of the 1990s. Trajectories of F after 1999 diverged among models; F remained steady in the predator-prey model, increased with the rescaled F analysis (but remained modest), and fell to a very low level with the Schaefer biomass dynamic model. Estimates of F from both time-series (1981-2003 and 1982-2003) used with the predator prey model were similar. Recent estimates of F from the Schaefer model exhibited the same pathology (trending in recent years to near zero; Figure 29) as estimates made with biomass dynamic models based on trawl survey indices (Uphoff 2005a).

Trends of estimates of $M_b$ were similar (increasing) through 2001 for Steele and Henderson models applied to the two time-series (Figure 30). Estimates of $M_b$ were below 0.05 through 1985 and then steadily increased to approximately 0.70 by 2001. Estimates diverged after 2001, $M_b$ based on the 1982-2003 time-series stabilized at about 0.7 while those based on 1981-2003 continued to increase to 1.1 by 2003 (Figure 30).

Trends in Z were similar between predator-prey models and the 1982-2003 ADAPT VPA (Figure 31); estimates of 1982-2003 $Z_b$ based on the 1981-2003 and 1982-2003 time-series were significantly correlated with $Z_{vpa}$ (Pearson r = 0.57, P < 0.005 and Pearson r = 0.53, P < 0.012, respectively). Total mortality rates estimated by the predator-prey model using the 1981-2003 time-series were high during 1982-1992 ($Z_b$ = 0.8-1.5), dropped significantly by 1995 ($Z_{bt}$ = 0.5-0.7), began a steady climb and returned to previous high levels by 2000, and continued to increase through 2003. Estimates of $Z_b$ based on the 1982-2003 time-series were similar to those from the other two approaches over most of the time-series, but were much lower in 2003. The 1982-2003 predator-prey model estimates of $Z_b$ plateaued at about 1.1-1.3 during 1998-2002 and then fell to just below 1.0 in 2003; these levels of $Z_b$ were only sustained previously during 1986-1989. Estimates of $Z_{vpa}$ have been between 0.9 and 1.4 since 2001; this sustained level was not evident in the ADAPT time-series since 1981-1992 (Figure 31).

Excluding 1981, weakfish biomass estimated by the predator-prey models did not exceed 20,000 mt (Figure 32). Biomass estimated from rescaled F analysis peaked at about 30,000 mt, while the Schaefer model estimates were as high as 60,000 mt. Predator-prey and rescaled F estimates of biomass were very similar in trend (declines and increases were concurrent) and magnitude of low biomass, but differed in magnitude of how high biomass could have been (Figure 32).

Striped bass-weakfish model estimates of weakfish biomass began to recover after 1990 and rose from 7,000 mt to 18,000 mt by 1997 (regardless of predator-prey model time-series). Increases in striped bass biomass beyond 70,000-80,000 mt were offset by decreases in weakfish biomass.

After 1997, weakfish biomass decline to about 8,000 mt. When weakfish biomass was added to striped bass biomass, an asymptotic combined biomass level of 100,000 -110,000 mt was suggested. This may represent the combined carrying capacity for these two species under the limited forage conditions in existence since the mid-1990s.

Alternative Predator-Competitors

Only striped bass commercial landings were significantly and negatively correlated (Pearson r = -0.35, P = 0.0095) with weakfish landings during 1950-2003 (Table 6). Bluefish and summer flounder landings during 1950-2003 had highly significant positive correlations (Pearson r = 0.73 and P < 0.0001 in both cases) with weakfish landings. Atlantic croaker harvests were marginally correlated with those of weakfish (Pearson r = 0.24, P = 0.08).

Trends in candidate species biomass during 1981-2003 varied (Figure 33). Striped bass exhibited a steady increase throughout, starting at about 5,000 mt and ending at about 100,000 mt. Summer flounder exhibited a general saddle shape trend – declining from 30,000 mt to 11,000 mt during 1981-1989, steadying at this low level until1994, and then steadily increased to 50,000 mt. Bluefish declined steadily from 150,000 mt until reaching 50,000 mt in the late 1990s; the stock stabilized for several years, and then increased to 90,000 mt over the last two years. Spiny dogfish steadily increased from 300,000 mt in the early 1980s to 560,000 mt by the early 1990s. Then they steadily decreased to about 400,000 mt (Figure 33).

Atlantic croaker biomass in the predator-prey model resulted in weakfish biomass estimates of about the same magnitude as that observed (biomass closeness ratio = 0.93), but did not produce a decline in recent years (Table 6, Figure 34). The croaker biomass time-series ended in 2002. Absence of an Atlantic croaker biomass estimate for 2003 is of concern because it was a crucial data point for producing a decline in biomass in predator-prey modeling of striped bass and weakfish. Estimates of r and K (1.00 and 53,823 mt, respectively) were similar to those for the striped bass-weakfish model. Parameter A (weakfish biomass where satiation occurs) estimated for the Atlantic croaker-weakfish model was greater than carrying capacity, casting doubt on the applicability of this model or at least the type III functional response to these data.

With bluefish as a predator, the Steele and Henderson model indicated that weakfish biomass was fluctuating about a mean level (Figure 35). Estimated biomass was about 10-times the observed level (closeness ratio = 0.08). There was little support for bluefish as an influential predator-competitor competitor based on the logistic Steele and Henderson model ($r^2 = 0.01$; Table 6).

Summer flounder biomass produced a similar trend in estimated biomass ($r^2 = 0.62$), but the estimates were 20% to 150% higher than the observed values (biomass closeness ratio = 0.56; Table 6, Figure 36). A recent decline in weakfish biomass was produced with summer flounder biomass as a predator. The intrinsic rate was about half that of the striped bass-weakfish model, while K was about 6-times higher (Table 6). Per capita consumption estimates (c = 1.2 mt tons consumed per mt of flounder) indicated flounder would need to consume over 15-times the amount weakfish as estimated for striped bass to produce a similar trend in biomass (Table 6).

Using spiny dogfish biomass estimates in the predator-prey model resulted in weakfish biomass estimates similar to those observed (closeness ratio = 0.89), but did not result in a good fit ($r^2$ = 0.29) or a decline in recent years (Table 6; Figure 37). Parameters r and K were similar to those in the striped bass-weakfish model; A was in excess of K, indicating this model was not entirely appropriate for examining the dogfish-weakfish relationship (Table 6).

Striped bass-weakfish landings analysis and predator-prey model results have already been described extensively and will not be described further here. Comparison of striped bass landings regression and predator-prey model results with other candidate species is presented in Table 6. Striped bass consumed weakfish directly and all five of the forage categories were well represented in diet studies reviewed (Table 7).

The ecological role of Atlantic croaker as a potential competitor or predator on weakfish is poorly understood but croaker trophic status is below that of weakfish (Hartmann et al. 1995; Miller et al. 2004). Diet information for Atlantic croaker were limited and confined to recent years in Chesapeake Bay (Miller et al. 2004). Weakfish were not listed as a diet item for Atlantic croaker. The only diet item on the scorecard that was consumed by Atlantic croaker was bay anchovy (Table 7).

Bluefish diets were summarized for both Chesapeake Bay (Hartman and Brandt 1995) and the North Atlantic and Mid-Atlantic coasts (Buckel et al. 1999a; 1999b). Weakfish were present at a low level in bluefish diets along the North and Mid-Atlantic (Buckel et al. 1999a; Table 7). Bay anchovy, Atlantic menhaden, spot, and clupeids were important items in at least one of the three studies (Table 8). Sciaenids other than spot and weakfish were present, but were a minor component of bluefish diets.

Summer flounder diets for the North and Mid-Atlantic were summarized in Bowman et al. (2000), Link and Almeida (2000), and Link et al. (2002a). Weakfish were present at a low level in summer flounder diets in the inshore region North of Cape Hatteras (Bowman et al. 2000; Table 8). Bay anchovy was the only candidate forage species specifically identified, while anchovies in general comprised less than 5% of summer flounder diets. Neither Atlantic menhaden nor spot were specifically mentioned, but clupeids generally comprised less than 10% of diet by weight. Sciaenids were a minor component of summer flounder diets (Table 8).

Rountree (1999), Link and Almeida (2000), and Link et al. (2002b) described spiny dogfish diets along the North and Mid-Atlantic region. Rountree (1999) reported that spiny dogfish prey on weakfish (Table 8). Only general categories containing our candidate species were identified: anchovies, clupeids, and sciaenids (Table 8). Clupeids were a major component of diet by weight, ranking second among all groups summarized in these two studies. Anchovies and sciaenids were minor components.

The weakfish predation-competition scorecard indicated that striped bass was by far the most likely predator-competitor candidate (9.5 out of 10 possible), followed by summer flounder (6.2), bluefish (6.1; 6.0 points due to diet studies), spiny dogfish (5.2), and Atlantic croaker (2.65; Table 8).

Summer flounder was the only candidate species beside striped bass to both have weakfish in its diet and reproduce the recent fall of weakfish biomass in predator-prey modeling. Based on these factors, summer flounder biomass was combined with striped bass in a predator-prey model run (hereafter, bass - flounder model).

The striped bass – flounder model fit the three predator-prey model criteria better than both species alone. The trend in biomass estimated from rescaled F analysis was faithfully reproduced (Figure 38). Fit of predicted biomass to observed improved ($r^2 = 0.83$). The ratio of predicted to observed biomass was close to 1 (0.95) and the decline in recent biomass was reproduced in the model (Figure 38). Model production parameters r and K (1.22 and 53,302 mt) and predator-prey functional response parameters (c = 0.096 and A = 2,976 mt) were much closer to those of striped bass than summer flounder (see Table 7). The shading of these parameters towards striped bass far exceeded the weighting expected based on biomass alone; average summer flounder biomass during 1982-2003 was 59% of striped bass biomass.

## DISCUSSION

At this time, weakfish have changed from a harvestable commodity to a supporting role as forage for the striped bass recovery (and perhaps other species recoveries). Weakfish in the Mid-Atlantic region are currently in a period of low productivity that has low forage abundance underlying it. Since the early to mid-1990s, regional (NC-NJ) indices of three important forage species (Atlantic menhaden, spot, and bay anchovy) have dropped to low levels. Under these conditions, their population dynamics are dominated by striped bass, perhaps with a negative contribution by summer flounder. Changes in weakfish size, abundance, and biomass dynamics were consistent with trends in forage relative abundance, striped bass and summer flounder biomass, and M over a broad geographic area and time-span. These changes supported the hypothesis that the aborted weakfish recovery largely reflected increased natural mortality due to striped bass competition and predation precipitated by depleted forage.

Equilibrium MSY limit reference points, consistent with the precautionary approach and estimated from the S-H model (Steele and Henderson striped bass-weakfish predator-prey model), indicated that F had been below the $F_{msy}$ limit for nearly a decade, but biomass had fallen well below the $B_{msy}$ limit in the last several years. Biomass was below $B_{msy}$ for most of the time-series, regardless of S-H model employed and F was below $F_{msy}$ since the early 1990s. Under equilibrium conditions, this should not be possible; fishing mortality rates in this range should have been associated with stock expansion or stability. S-H models indicated these equilibrium-based biological reference points have limited utility in this situation where M is rising rapidly. Biological reference points can be sensitive with species subject to predation and cannibalism and may represent moving targets (Collie and Gislason 2001). In the case of the striped bass-weakfish model, by 2003 rising $M_b$ ate away at the amount of F that represented a level of "safe" fishing; $r - M_b$ fell from 0.66 in 2001 to 0.08 in 2003. Even though F fell from 0.50 during 2000-2002 to 0.39 in 2003, the amount of residual productivity ($r - M_b - F$) went from positive to negative (0.16 to -0.31) during 2000-2003.

Natural mortality of age 1+ weakfish was originally assumed to be constant across ages and years (M = 0.25; NEFSC 1998; 2000). We found that the trend in annual natural mortality

estimates during1982-2003 did not support the constant M assumption. Striped bass-weakfish predator-prey models corroborated the rise in M over the past decade. In future assessments here and elsewhere, the assumption of constant M for ages 1+ fish needs to be critically examined. The weakfish ADAPT VPA assumes constant natural mortality (Part 1). Misspecification of M in a VPA creates particularly large biases for lightly fished stocks and, when combined with changes in F, leads to a time-varying bias (Mertz and Meyers 1997).

For medium-term advice, it may suffice to consider one-way interactions and categorize each species as predator or prey (Collie and Gislason 2001). This simplification, which we employed in our S-H models, is convenient because it allows predators to be added to a single species assessment (Collie and Gislason 2001). However, Walters and Martell (2004) warned that this approach does not recognize how trophic ontogeny may cause more complex dynamics.

Biomass dynamic models implicitly assume that underlying ecological conditions remain unchanged (variations in stock size reflect random variation and fishing; Spencer and Collie 1997). Without an additional predator-competitor term, a Schaefer model based on WRI indicated that biomass was continuing to increase and F was falling to a very low level. This same unrealistic trend was produced by trawl index-based biomass dynamic models (Uphoff 2005a). After modeling under an ecological stability assumption, we were left with concluding that recreational and commercial fishers were no longer interested in harvesting a high population of weakfish or that the population was so high that they stunted at smaller sizes than are of interest (Uphoff 2005a). Decreasing forage and increasing competition among predators make it appear unlikely that ecological conditions were stable over the time span modeled.

Term c (per capita consumption by striped bass) in the predator-prey model represented combined effects of direct striped bass predation, but it could be that cannibalism and starvation induced by intense competition with striped bass were being described as well. Predators' responses to prey can be divided into a functional response (number of prey consumed per unit area per unit time by an individual) and a numerical response (numbers change with prey density; Yodzis 1994; Bax 1998). Numerical response to prey density may have a direct development component (growth, birth, and death), but interaction with other predators may also influence this response (Bax 1998). Individual predators may interfere with one another in a number of ways that might affect population growth (Yodzis 1994). Among these interactions, the ones most relevant to weakfish and striped bass would be (1) they may hinder one another's feeding activities, leading to starvation; (2) they may eat one another (including cannibalism); (3) they may indulge in territorial behavior; and/or (4) they may emigrate (Yodzis 1994).

Striped bass did not appear tightly linked to weakfish as prey and loss of weakfish at high recent striped bass population size represented collateral damage. Versions of the 1981-2003 or 1982-2003 logistic predator-prey models, where c was a constant multiplied by striped bass biomass to estimate bass-related weakfish losses ($D_t = c \bullet P_t$) instead of a type III function, produced similar estimates of r and c, but more variable estimates of K, as logistic models employing a sigmoid predator-prey function. Variations in c were particularly important; both trials with linear predator-prey functions produced estimates of c (0.073 and 0.069 for 1981 and 1982 as initial years, respectively) that were similar to the 1981-2003 sigmoid function model estimate (c = 0.076). In the case of the 1982-2003 time-series logistic model, a constant c improved fit over

the sigmoid version (linear model SSQ = 2.49, sigmoid SSQ = 2.71). Only the sigmoid model of the 1982-2003 time-series supported the concept of striped bass predation dependent on the biomass of weakfish. The three other versions of the logistic predator-prey model indicated striped bass related mortality was depensatory. Trends in biomass, F , and $M_b$ from constant c were quite similar to those presented for sigmoid functions.

In this analysis, there was a good chance that striped bass represented predators that were not tightly linked to weakfish, a secondary prey. Depensatory mortality may exist when a fish population is faced with a predator that spends much of its time feeding on one prey species, but also has secondary prey (Hilborn and Walters 1992). Predator abundance may be independent of the secondary prey and if the predators are efficient at finding and capturing secondary prey, then the number eaten will be more or less constant. As primary prey abundance declines, the mortality rate caused by the predators on the secondary prey increases (Hilborn and Walters 1992). As indicated by Spencer and Collie (1997), fish stocks that are subject to moderate to severe depensatory predatory mortality often undergo a sudden and persistent drop in surplus production over time, even when fishing mortality rates have remained low for several years.

There is little experience to judge the suitability of parameter A (weakfish biomass where predator satiation begins) in the type III predation function. The ratio of A/K in the 1981-2003 logistic weakfish - striped bass model (0.04) was comparable to estimates generated by Spencer and Collie (1995; 1997) for Georges Bank haddock and spiny dogfish (0.05 – 0.07). Dogfish were considered a depensatory predator of haddock (Spencer and Collie 1995; 1997b). The ratio of A/K in the 1982-2003weakfish logistic predator-prey model (with Type III function) was considerably higher (0.23) and would indicate a more density-dependent relationship.

The "effect" of these different predator-prey relationships estimated from the two time-series (1981-2003 or 1982-2003) may be best illustrated by exploratory projections. In these projections, striped bass biomass was held constant at its 2003 level through 2022. A constant exploitation rate of 0.1 was set after 2004 (a rate higher than this crashes the 1981-2003 based model). With c = 0.76 and A = 1,956 mt (estimates from1981-2003), the population stabilized by 2010 at very low biomass (555 mt). With c = 0.155 and A = 11,387 mt (estimates from 1982-2003 time-series), the population increases to about 23,300 mt by 2022.

Unlike harvest, we are unlikely to ever have a natural mortality "body count" to unequivocally estimate M. Results from regression and production models demonstrate striped bass-weakfish linkage and they are consistent with studies of striped bass predation in the mid-Atlantic. Weakfish have been specifically identified as a food item in some, but not all, striped bass diet studies in the mid-Atlantic region. They have appeared in studies conducted in lower Chesapeake Bay (Austin and Walter 1998) and Ablemarle Sound (Manooch 1973). They were infrequent diet items, comprising about 1-8% of diets by number and 2-3% on a weight or volume basis (Manooch 1973; Austin and Walter 1998). Weakfish were present in striped bass larger 400 mm in lower Chesapeake Bay in fall and winter (Austin and Walter 1998), while they were present in striped bass larger than 300 mm in Ablemarle Sound during "cooler" months (Manooch 1973). During winter 2004-2005, weakfish comprised 5% of striped bass diets by weight along North Carolina's coast (A. Overton, East Carolina University, personal communication).

Significant ($P < 0.10$) positive associations of weakfish size quality (1966-2003 DE PSD Q+ index) and forage abundance occurred consistently (but not among all surveys) in MD and VA for all three species and sporadically in NJ and NC. Regressions of striped bass biomass and juvenile menhaden abundance against DE PSD Q+ indicated a significant positive influence of forage and negative influence of striped bass on weakfish size quality. The DE PSD Q+ index represented the longest time-series of fishery-independent data on weakfish population dynamics. Length-frequency data, indexed by DE PSD Q+, contains much of the information contained in age-frequency data and even cursory examination of a length-frequency can give useful insights into population dynamics of a stock (Powell 1979; Hoenig et al. 1987). A population's length-frequency distribution results from its recent history of recruitment and mortality, integrated with growth (Barry and Tegner 1989). Two major parameters affecting DE PSD Q+, growth and mortality, have likely been influenced directly by competition for limited forage and predation.

The DE PSD Q+ index could have been influenced by trends in recruitment; size quality could have diminished because of recent recruitment of strong year-classes. Recruitment indices for weakfish in Crecco (2006) have exhibited wide regional variation, but the overall trend of the grand mean has been an increase during the 1990s and stabilization at a high level afterward (Figure 39). However, juvenile mortality has risen (Crecco 2006), while landings and other relative abundance or biomass indices have declined to well below average during 2002-2004. If the DE PSD Q+ index was to decline due to strong recruitment alone, then these abundance indicators and landings should be increasing.

The PSD Q+ index was chosen over growth equations because a long-time series of otolith-based growth estimates was not available and of because uncertainties in growth estimation. Otoliths were not primary aging media until the early to mid-1990s (NEFSC 1998). Fitting von Bertalannfy growth curves to these data has not been straightforward. Kahn (2002b) estimated von Bertalannfy curves by assigning constant asymptotic maximum length ($L_\infty$) of 765 mm because of implausible estimates of this parameter; this same step was necessary to update 2001-2003 growth equations. Estimates of remaining von Bertalannfy parameters could have been confounded because they are interrelated (Jensen 1997). If assignment of constant $L_\infty$ represents a real phenomenon, a 17% loss in maximum size (from 919 mm) has occurred since the otolith-based estimate made by Lowerre-Barbieri et al. (1995) for the early 1990s.

Kahn (2002b) described a decreasing trend in weakfish Brody growth coefficients in von Bertalannfy growth equations estimated for weakfish during 1990-1999. The Brody growth coefficient dropped by over half after 1990-1992 (Kahn 2002b). Kahn (2002b) also noted lower mean weights-at-age estimated for 2000 than those estimated for 1989-1992 by Lowerre-Barbieri et al. (1995). Weakfish weight-at-age has exhibited large drops since 1992 and the magnitude of the decline increased with increasing age. These changes corresponded to decreased forage relative abundance and increased striped bass biomass.

Significant decreases in weight-at-age of weakfish implied a corresponding rise in natural mortality. Natural mortality rates of fishes increase as a nonlinear function of decreasing body mass under equilibrium conditions when mortality is primarily derived by predation (Peterson and Wroblewski 1984; Boudreau and Dickie 1989).

Median weights-at-age of weakfish of 3 year-old weakfish during 1993-2003 were 75% of those during 1981-1992, while those of ages 4 and 5 during 1993-2003 were 55%. These changes in weight suggest that starvation-related mortality was possible for weakfish and indicated that older weakfish would be most likely to be subjected to starvation. Mortality due to starvation is a size-dependent process (Persson and Bronmark 2002). In a simulation of ontogenetic predator-prey dynamics of pikeperch, Persson and Bronmark (2002) assumed starvation occurred if individual weight dropped below 70% of weight predicted by a length-weight equation. In experiments with fasting juvenile rainbow trout, mean wet weight of starved fish that died were 77% of weight at the beginning of the experiment (Simpkins et al. 2003). A weight-based prediction of starvation is likely to be pretty coarse and may not correspond to the point where protein is broken down to meet metabolic demands (J. Jacobs, NOAA, personal communication).

Declines in weakfish mean weight exhibited in the weight-at-age matrix reflected a bottleneck of appropriate sized prey (juvenile menhaden and spot). If weakfish have stunted at these diminished weights because of low forage availability, this stunted size should reflect the size of forage needed. In experiments, Hartman (2000) found that peak profitability for striped bass occurred at a ratio of prey weight to predator weight of 0.12. When this ratio is applied to weakfish median weight-at-age estimates for 2-5 year-olds since 1993, it indicates that prey weighing an average of 29-109 grams (prey size increasing with weakfish age) would have been most profitable. These weights corresponded to menhaden (growth parameters in ASMFC 2004a) or spot (Fishbase parameters; www.fishbase.org) less than one year-old.

Atlantic menhaden is a buffer species that absorbs predatory pressure from other species when they are sufficiently abundant (ASMFC 2004b). Striped bass actively select for Atlantic menhaden, but will feed on other species when menhaden are not sufficiently abundant (Overton 2003; ASMFC 2004b; Ruderhausen et al. 2005) and they appear capable of limiting their prey populations along the Atlantic coast (Hartman 2003). As menhaden have become less abundant, striped bass searching is likely to lead to increasing encounters with vulnerable-sized weakfish (Walters and Martel 2004) reflected in the close correspondence of weakfish mortality and striped bass biomass.

Attack success of striped bass on Atlantic menhaden has likely been falling (Uphoff 2003). As the ratios of biomass of age 2+ striped bass to: biomass of age 0-2 menhaden (or biomass of bass big enough to eat menhaden: biomass of menhaden small enough to be eaten; based on ASMFC assessments; Uphoff 2003) along the Atlantic Coast fell to asymptotic lows in the mid-1990s, natural mortality of weakfish rose (as indicated by $M_{vpa}$, $M_{b,}$ and the estimated trend of juvenile mortality; Crecco 2006; Figure 40). Potential attack success of striped bass on menhaden would be indexed by this ratio because a predator's functional response (number of prey consumed per unit area, per unit time by an individual predator) is both a function of attack success and prey handling time (Yodzis 1994). Handling time varies little for a given predator (Yodzis 1994). Predator feeding efficiency will be inversely related to prey density as consumption rate declines and search effort increases (Ney 1990).

Hartman and Brandt (1995) found striped bass in Chesapeake Bay increased their use of the pelagic food web (primarily menhaden) as they aged, while weakfish increased use of benthic

resources (spot). Stable isotope analysis of striped bass scales collected during 1982-1997 from Chesapeake Bay indicated striped bass increased their use of the benthic food web as menhaden abundance decreased (Pruell et al. 2003). This shift would place them in more direct competition with weakfish and increase the chance striped bass would be occupying the same habitat as weakfish while feeding.

The percent of weakfish and striped bass diets represented by menhaden in Chesapeake Bay dropped substantially between the early 1990s and 2000s (Hartman and Brandt 1995; Overton 2003; Bonzek et al. 2004). The menhaden fishery, centered in Chesapeake Bay, harvests larger menhaden than those consumed by most weakfish or smaller striped bass (ASMFC 2004b), but direct competition with large striped bass is possible. Generalizations of functional response suggested that the fishery would outcompete striped bass at low menhaden densities (Uphoff 2003). A prey-size cascade could have been precipitated by competition between large striped bass and the fishery. Large striped bass are now relying more on small pelagic prey (bay anchovy and juvenile clupeids) needed by small striped bass and weakfish, while diets of these smaller piscivores have shifted to benthic invertebrates (see below; Griffin and Margraf 2003; Overton 2003). Slowing of weakfish growth due to a diet bottleneck, in turn, leaves them more vulnerable to striped bass predation, as do increased searching times for juvenile weakfish attempting the transition to piscivory. Increased searching time for small weakfish to obtain anchovy increases their exposure to larger striped bass that are now competing for the same resource. There is a horrific linkage between getting food and being food (Walters and Martell 2004).

Spot harvests in the mid-Atlantic are considerably less than those of the menhaden fishery, but their impact in relation to the population is unknown because a stock assessment is lacking. Bycatch in shrimp fisheries would kill spot at a size needed by weakfish and striped bass; however, shrimp fisheries do not operate in the geographic range (NJ-VA) where depletion of spot was suggested by correlation analysis. Pamlico Sound (NC) spot indices did not suggest depletion where substantial shrimp bycatch might have been expected. Striped bass generally do not range into Pamlico Sound (Boreman and Lewis 1987).

Weakfish biomass estimated for 1981 with the S-H model exceeded the estimate of K by nearly 30%, was over three-times the next highest biomass, and generally appeared as an outlier in most time-series and bivariate plots with other parameters. However, it could also have indicated rapid initiation of a regime shift in weakfish production. This year (1981) was the last year of an extraordinary three-year period of high landings, maximum DE PSD Q+, and trophy catches (Uphoff 2005a). A speculative Schaefer biomass dynamic model of an extended time-series (1975-2003; Uphoff 2005a) indicated that by 1981 weakfish biomass was in rapid decline from a period of very high biomass. This extended time-series analysis was similar in trend over years in common to the Schaefer biomass dynamic model included in comparisons with the predator-prey model. Estimates of stock biomass trends were in general agreement among models featured in this analysis until the late 1990s, when the Schaefer biomass dynamic model estimates began to diverge from S-H model estimates.

A negative relationship of Atlantic Coast striped bass and weakfish landings that reflected one high (1970s - 1980s) and two low periods (1950s -1960s, and 1990s -current) of underlying

weakfish productivity was indicated by categorical and multiple regression analyses of 1950-2003 weakfish and striped bass commercial landings, LBI, and indicators of Atlantic menhaden juvenile abundance. Earlier landings appear to confirm the negative relationship between these species' landings and rapid changes in weakfish status. Commercial records for these two species were intermittent from 1887-1950, but were reasonably frequent by the late 1920s (Joseph 1972; Boreman and Austin 1985). Catches of weakfish were generally high during the late 1920s through the mid-1940s while striped bass landings were low, but rising. Weakfish landings collapsed within four years in the late 1940s, while striped bass landings continued a sustained increase that lasted into the early 1970s (Joseph 1972; Boreman and Austin 1985). Correlations with landings of other four other candidate predator-competitors did not suggest a significant negative interaction.

Generally, autocorrelated variability that mimics long-term environmental patterns has been the forcing function that underlies regime shifts in simulations of populations with the S-H model (Steele and Henderson 1984; Collie and Spencer 1993; Spencer and Collie 1995; Spencer and Collie 1997a). Movement from high to low equilibrium states can be induced by increased fishing and depensatory mortality (Collie and Spencer 1993). Additional stress, usually attributed to fishing, reduces the level of environmental perturbation necessary to flip a system into a low equilibrium state (Collie and Spencer 1993) and causes flips to occur with higher frequency (Steele 1996). In the recent case of weakfish, it is likely depensatory mortality associated with striped bass under low forage conditions is the force leading to low productivity. The regime shift concept implies that different regimes have inherent stability, so that significant forcing is required to flip the system into alternative states (Steele 1996). The simple models for regime shifts have only two states, but nature may more complex and returning to a desired state may not be guaranteed by reduced fishing on weakfish, increased fishing on striped bass, or betting on beneficial environmental change (Steele 1996).

It is not possible to look at all predation processes in a fishery ecosystem (Bax 1998; Sainsbury 1998) and we have concentrated on a limited representation of the food web. Atlantic menhaden, spot, and bay anchovy represented 65-99% of total prey consumed by striped bass and weakfish during their estuarine residency in Chesapeake Bay during the early 1990s (Hartman and Brandt 1995). Atlantic menhaden and bay anchovy accounted for nearly 65% of weakfish diets by weight in Delaware Bay during 1985 (Taylor 1987). Clupieod fishes (herrings and anchovies) have dominated the diets of striped bass above age 1 (Walter et al. 2003). Summer and fall diets of striped bass were dominated by these three forage species in Chesapeake, Delaware, and North Carolina regions (Walter et al. 2003). Young-of-year weakfish feed on mysid shrimp and bay anchovy, while older weakfish feed on clupeid species that are abundant in a given area (Mercer 1985; Hartman and Brandt 1995). Striped bass evolved as a schooling species to take advantage of the great energy resource of clupeids along the Atlantic Coast (Stevens 1979). Diet studies strongly suggest that these two piscivores compete strongly for the same forage resources and changes in population characteristics such as growth, mortality, and abundance could be linked under conditions of scarce forage.

Weakfish diet studies have been infrequently conducted in the recent past. Age-specific weakfish diets (ages 0-2) were described by Hartman and Brandt (1995) during 1990-1992 in mid-Chesapeake Bay, while Virginia Institute of Marine Science's Chesapeake Bay Multispecies

Monitoring and Assessment Program (ChesMMAP) characterized age-specific diets of weakfish (ages 0-5) in the entire Bay during 2002-2003 (Bonzek et al. 2004). These latter data were presented at the 2004 American Fisheries Society Meeting and were provided for this analysis (R. Latour, VIMS, personal communication). We have limited the following discussion to Atlantic menhaden, spot, bay anchovy, and invertebrates. Diets in Hartman and Brandt (1995) preceded decreases in forage relative abundance and weakfish weight-at-age, while those described in Bonzek et al. (2004) represent recent conditions of depleted forage and reduced weight-at-age.

Weakfish diet studies in Chesapeake Bay have indicated major changes in the past decade. Atlantic menhaden, spot, bay anchovy, and invertebrates comprised over 75% of diets, by weight, during 1990-1992 and 2002-2003 (Figure 41). Bay anchovy and Atlantic menhaden have become much less frequent in weakfish diets between the early 1990s and early 2000s, spot have disappeared, and invertebrates have comprised a greater part of the diet.
Weakfish in Chesapeake Bay during both periods made a rapid transition to piscivory - bay anchovy dominated their diets as young-of year. However, transition from bay anchovy to dominance of spot and Atlantic menhaden at age 2 that occurred during the early 1990s was not evident in recent years. Older weakfish (ages 2+) are subsisting on the same invertebrate and bay anchovy diet as ages 0-1, with a much smaller supplement of menhaden (Figure 41). Striped bass diets in Chesapeake Bay have undergone similar changes as those described for weakfish; small striped bass are now relying more on invertebrate prey and large striped bass on small pelagic prey such as bay anchovy and age 0 clupeids, and benthic invertebrates (Griffin and Margraf 2003; Overton 2003). This suggests that larger prey (juvenile menhaden and spot) were insufficiently available for both species to complete the transition to piscivory.

Weakfish are cannibalistic; weakfish juveniles were specifically mentioned in diet studies reviewed by Mercer (1985) and comprised about 20% of weakfish diet by weight in Delaware Bay during 1985 (Taylor 1987). Weakfish were not specifically mentioned in Chesapeake Bay diets during 1990-1992 (Hartman and Brandt 1995), but other weakfish comprised 10% of age 2 and 6% of ages 3-5 diets in Chesapeake Bay during 2002-2003 (R. Latour, VIMS, personal communication). Increased cannibalism could be a consequence of weakfish's inability to compete with striped bass for other forage fish.

Discussions between the Weakfish Stock Assessment Subcommittee (WSAS) and the 40$^{th}$ SARC panel spawned the multiple hypothesis approach adopted by the WSAS to deal with conflicting signals in the data and analyses in this assessment. This approach led the WSAS to formulate and test, and reformulate and retest alternative hypotheses about M to explain patterns in the underlying data. This assessment strategy indicated the likelihood that the dynamics of striped bass predation and competition, and regime change took over in the 1990s once overharvesting had been controlled. Models used in this investigation were of intermediate complexity because of the basic limitations of the observational data. Simplified procedures allowed for the testing of overfishing and ecological hypotheses; overfishing was not supported as the sole cause of the recent decline.

Because of the large numbers of inputs into complex age-structured models, other parameters that may be indicative of other underlying dynamics (growth, productivity, recruitment, natural

mortality, spatial dynamics, fishing efficiency, and fishing selectivity) are held constant or ignored. This assessment strategy must become less favored in light of realization that the dynamics of predation, competition, environmental regime shifts, and habitat alteration or deterioration may take over once overharvesting has been controlled (Link 2002). Simply presuming that ceasing exploitation on an overfished stock will result in recovery ignores the uncertainty imposed by ecological systems (Link 2002). Stationarity of ecological conditions or constancy of M cannot be an acceptable default assumption (Sainsbury 1998).

We do not advocate abandoning more complex age-structured models, but are advocating testing the overfishing hypothesis with less time-consuming methods before plunging into their application. If these less intensive methods (trend analyses, relative F, year-class catch curves, and surplus production models, for example) lend some support to F as a major contributor to the dynamics in question, then proceed with more intensive analysis. If the hypothesis that fishing is a major contributor to a decline is not well supported, time should be spent pursuing alternate explanations.

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## TABLES

**Table 1**. Descriptions of surveys used as estimates of forage relative abundance in the mid-Atlantic region. MH = Atlantic menhaden, S = spot, and BA = bay anchovy.

| Location | Gear | Time-series | Estimator | Source | Species |
|---|---|---|---|---|---|
| NC, Ablemarle Sound | Seine | 1972-2002 | Geometric mean | L. Paramore, NC DMF | MH |
| NC, Ablemarle Sound | Seine | 1972-2002 | Delta log-normal | ASMFC 2004a | MH |
| NC, Pamlico Sound | 16 ft trawl | 1988-2002 | Arithmetic mean | L. Paramore, NC DMF | S |
| VA, Chesapeake Bay | Seine | 1967-1973, 1980-2003 | Geometric mean | www.fisheries.vims.edu | MH, S, BA |
| MD, Chesapeake Bay | Seine | 1959-2003 | Presence-absence | E. Durell, MD DNR | MH<br>S, BA |
| MD, Coastal Bays | 16 ft trawl | 1972-2003 | Geometric mean | Casey and Doctor (2004) | S, BA |
| DE, Delaware Bay | 30 ft trawl | 1966-1972, 1980-1984, 1990-2002 | Arithmetic mean | Michels and Grecco (2003) | MH, S |
| DE, Delaware Bay | 16 ft trawl | 1980-2002 | Arithmetic mean | Michels and Grecco (2003) | S, BA |
| NJ, Delaware Bay | Seine | 1980-2003 | Arithmetic mean | J. Brust, NJ DEP | MH, S, BA |

**Table 2**. Weakfish landings (mt commercial and recreational, including discards), weakfish biomass indices (WRI, kg catch per trip), and striped bass biomass (mt) estimates used as inputs for the logistic predator-prey model.

| Year | Weakfish Harvest | WRI | Striped Bass |
|---|---|---|---|
| 1981 | 20814 | 0.96 | 6236 |
| 1982 | 13823 | 0.46 | 5495 |
| 1983 | 14426 | 0.5 | 4656 |
| 1984 | 13338 | 0.31 | 6532 |
| 1985 | 11181 | 0.28 | 6794 |
| 1986 | 15590 | 0.42 | 7701 |
| 1987 | 11691 | 0.35 | 11741 |
| 1988 | 13090 | 0.3 | 14739 |
| 1989 | 8136 | 0.13 | 20402 |
| 1990 | 5440 | 0.09 | 24857 |
| 1991 | 5610 | 0.1 | 28655 |
| 1992 | 4793 | 0.14 | 35771 |
| 1993 | 4448 | 0.09 | 41806 |
| 1994 | 5395 | 0.19 | 49611 |
| 1995 | 5977 | 0.29 | 60005 |
| 1996 | 6879 | 0.38 | 70322 |
| 1997 | 7206 | 0.34 | 78778 |
| 1998 | 7809 | 0.44 | 83480 |
| 1999 | 6219 | 0.38 | 84275 |
| 2000 | 6126 | 0.42 | 85650 |
| 2001 | 5369 | 0.24 | 95746 |
| 2002 | 4434 | 0.24 | 89280 |
| 2003 | 2660 | 0.12 | 104282 |

**Table 3**. Variables and scoring criteria for the candidate species "scorecard". RF = rescaled F analysis (Crecco 2005) and PP = predator-prey model.

| **Variable** | **Scoring criterion** |
|---|---|
| 1950-2003 landings correlation | 1 if significant and negative, 0 otherwise. |
| Biomass correlation | 1981-2003 RF and PP estimates $r^2$ = score |
| Recent decline | 1 if decline and 0 otherwise |
| Biomass closeness | Mean RF: mean PP or mean PP:mean RF, whichever < 1 |
| Weakfish in diet | Absent or present, 0 or 1 |
| Bay anchovy in diet | Absent or present, 0 or 1 |
| Atlantic menhaden in diet | Absent or present, 0 or 1 |
| Spot in diet | Absent or present, 0 or 1 |
| Clupieds in diet | Absent or present, 0 or 1 |
| Scianeids in diet | Absent or present, 0 or 1 |

**Table 4**. Correlations of relative abundance of major weakfish forage species in Mid-Atlantic region surveys and the DE Trawl Survey Quality+ PSD. Pearson correlation coefficient = r. Grey highlights indicate significant at P < 0.1 after adjustment for multiple comparisons. Ablemarle Sound correlations depict two estimators of central tendency applied to the same data.

| State | Survey | Menhaden (r, P) | Spot (r, P) | Bay Anchovy (r, P) |
|---|---|---|---|---|
| NJ | DE Bay Seine | -0.35, 0.137 | 0.68, 0.0015 | 0.22, 0.368 |
| NJ | Ocean trawl CPUE, number | | | -0.43, 0.129 |
| NJ | Ocean trawl CPUE, weight | | | -0.36, 0.209 |
| DE | 16 foot DE Bay Trawl | | 0.13, 0.601 | -0.27, 0.277 |
| DE | 30 foot DE Bay Trawl | -0.43, 0.040 | -0.09, 0.669 | |
| MD | Coast Bays 16 ft trawl | | 0.49, 0.03 | 0.61, 0.0063 |
| MD | Chesapeake 100 ft seine | 0.79, <0.0001 | 0.73, <0.0001 | -0.163, 0.427 |
| VA | Chesapeake 100 ft seine | 0.60, 0.004 | 0.54, 0.009 | 0.63, 0.0016 |
| VA | 30 foot trawl, Chesapeake | | 0.39, 0.088 | -0.52, 0.025 |
| NC | Ablemarle Sound Seine GM | 0.33, 0.159 | | |
| NC | Ablemarle Sound Seine Delta log-normal | 0.64, 0.003 | | |
| NC | Pamlico Sound Trawls | | -0.22, 0.439 | |
| Coastwide | Abundance estimate | 0.71, <0.0001 | | |

**Table 5**. Sensitivity of logistic Steele-Henderson predator-prey (striped bass-weakfish) model parameters to different time-series. Original treatment is the 1981-2003 time-series. Parameter r is the intrinsic rate of increase, K = carrying capacity (mt), $B_0$ = initial biomass of time-series, c = per capita consumption of weakfish by striped bass, A is weakfish biomass where satiation of striped bass occurs, and mean q is average catchability.

| Treatment | r | K | Bo | c | A | Mean q |
|---|---|---|---|---|---|---|
| Original | 1.17 | 49080 | 65275 | 0.076 | 1959 | 0.000020 |
| end 2002 | 1.14 | 49080 | 65262 | 0.084 | 9242 | 0.000020 |
| end 2001 | 1.11 | 49081 | 65146 | 0.082 | 12500 | 0.000019 |
| end 2000 | 1.08 | 49080 | 65298 | 0.076 | 20335 | 0.000018 |
| start 1982 | 1.26 | 49139 | 16744 | 0.155 | 11387 | 0.000020 |
| start 1983 | 1.23 | 48738 | 16738 | 0.164 | 14824 | 0.000020 |
| start 1984 | 1.22 | 43989 | 16744 | 0.155 | 15705 | 0.000020 |
| 1981 fixed | 1.16 | 44719 | 49000 | 0.279 | 27293 | 0.000020 |

**Table 6**. Estimates of logistic predator-prey model parameters r, K , and c (per capita effect of weakfish by striped bass) under sigmoidal and linear (constant) striped bass predation functions. SSQ is the sum of squared deviations of observed and predicted WRI indices.

| Time-series | Predator function | r | K (mt) | c | SSQ |
|---|---|---|---|---|---|
| 1981-2003 | Sigmoid | 1.17 | 49,080 | 0.076 | 2.62 |
| 1982-2003 | Sigmoid | 1.26 | 49,139 | 0.155 | 2.71 |
| 1981-2003 | Linear | 1.09 | 55,136 | 0.073 | 2.89 |
| 1982-2003 | Linear | 1.25 | 37,883 | 0.069 | 2.49 |

**Table 7**. Summary of results of analyses of candidate predator-competitors and weakfish. Model refers to a logistic Steele and Henderson (1984) predator-prey model . "Recent decline?" indicates that the predator-prey model with weakfish produced a decline in weakfish biomass in the most recent years. Biomass ratio is the ratio of predicted to observed (or vice-versa, depending on which is < 1) 1981-2003 mean biomass estimates. Parameter r = intrinsic rate of population increase; K = maximum population biomass (mt); maximum c is per capita consumption by candidate predator; A is weakfish biomass (mt)where predator satiation begins.

| | **Atlantic croaker** | **Bluefish** | **Summer flounder** | **Spiny dogfish** | **Striped bass** |
|---|---|---|---|---|---|
| **Landings Pearson correlation** | r = 0.24<br>P = 0.08 | r = 0.73<br>P < 0.0001 | r = 0.73<br>P < 0.0001 | NA | r = -0.34<br>P = 0.01 |
| **Predator-prey model $r^2$** | 0.72 | 0.01 | 0.62 | 0.29 | 0.78 |
| **Recent decline?** | No | No | Yes | No | Yes |
| **Biomass ratio** | 0.93 | 0.08 | 0.56 | 0.89 | 0.73 |
| **r (intrinsic rate)** | 1.00 | 2.92 | 0.62 | 1.22 | 1.17 |
| **K (mt)** | 53,823 | 296,109 | 293,653 | 56,672 | 49,080 |
| **c** | 0.398 | 1.198 | 1.190 | 0.214 | 0.076 |
| **A (mt)** | 88,414 | 90,377 | 43,843 | 92,115 | 1,959 |

**Table 8**. Scorecard for candidate species interaction with weakfish. Scoring criteria are explained in Table 3. Potential maximum score = 10 and indicates how strong a candidate a species would be for negative interactions with weakfish.

| | Score | | | | |
|---|---|---|---|---|---|
| **Variable** | **Atlantic croaker** | **Bluefish** | **Summer flounder** | **Spiny dogfish** | **Striped bass** |
| **Landings correlation** | 0 | 0 | 0 | 0 | 1 |
| **Biomass correlation** | 0.72 | 0.01 | 0.62 | 0.29 | 0.78 |
| **Recent decline** | 0 | 0 | 1 | 0 | 1 |
| **Biomass closeness** | 0.93 | 0.08 | 0.56 | 0.89 | 0.73 |
| **Weakfish in diet** | 0 | 1 | 1 | 1 | 1 |
| **Anchovy in diet** | 1 | 1 | 1 | 1 | 1 |
| **Menhaden in diet** | 0 | 1 | 0 | 0 | 1 |
| **Spot in diet** | 0 | 1 | 0 | 0 | 1 |
| **Clupieds in diet** | 0 | 1 | 1 | 1 | 1 |
| **Scianeids in diet** | 0 | 1 | 1 | 1 | 1 |
| **Score (sum)** | 2.65 | 6.09 | 6.18 | 5.18 | 9.51 |

## FIGURES

**Figure 1.** Atlantic Coast commercial landings of weakfish, striped bass, Atlantic croaker, summer flounder, and bluefish.

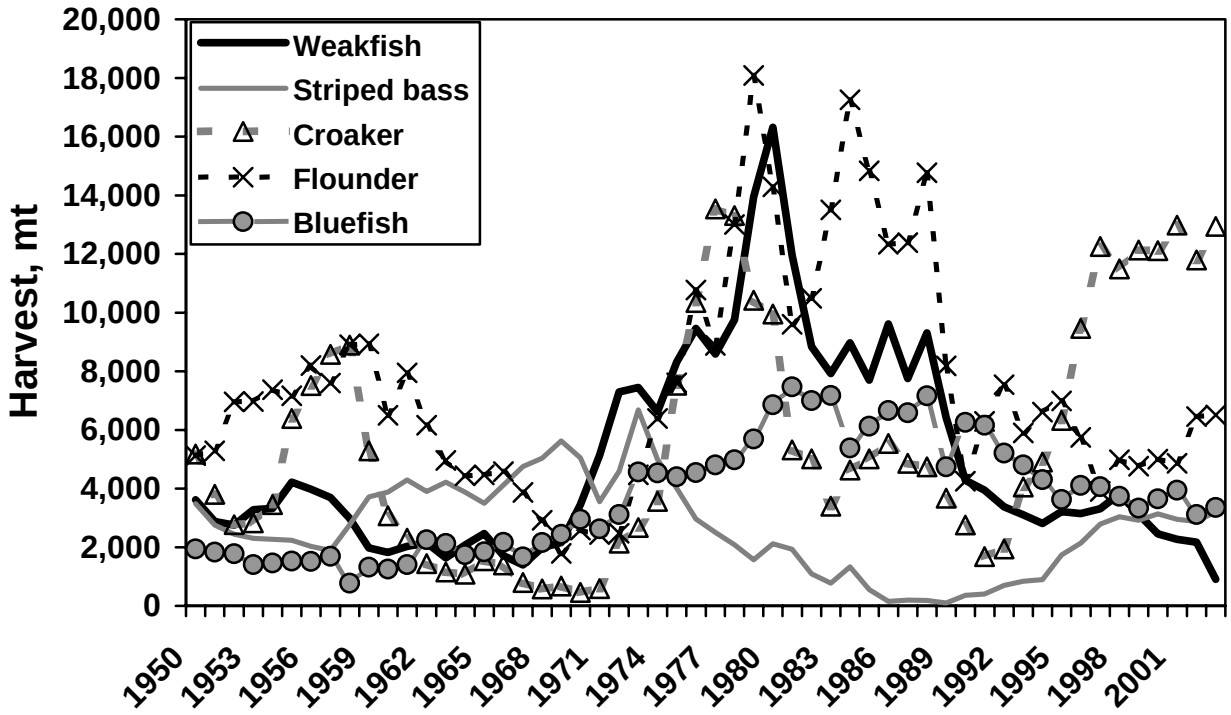


**Figure 2.** Relative abundance or biomass indices for weakfish. WRI is an MRFSS catch per trip index and equals MRFSS estimates of private/rental catch per trip in mid-Atlantic state waters (harvest and releases). Delaware and New Jersey trawl survey exploitable biomass indices estimated relative biomass of 25 cm and larger weakfish and are z-transformed values plus one.

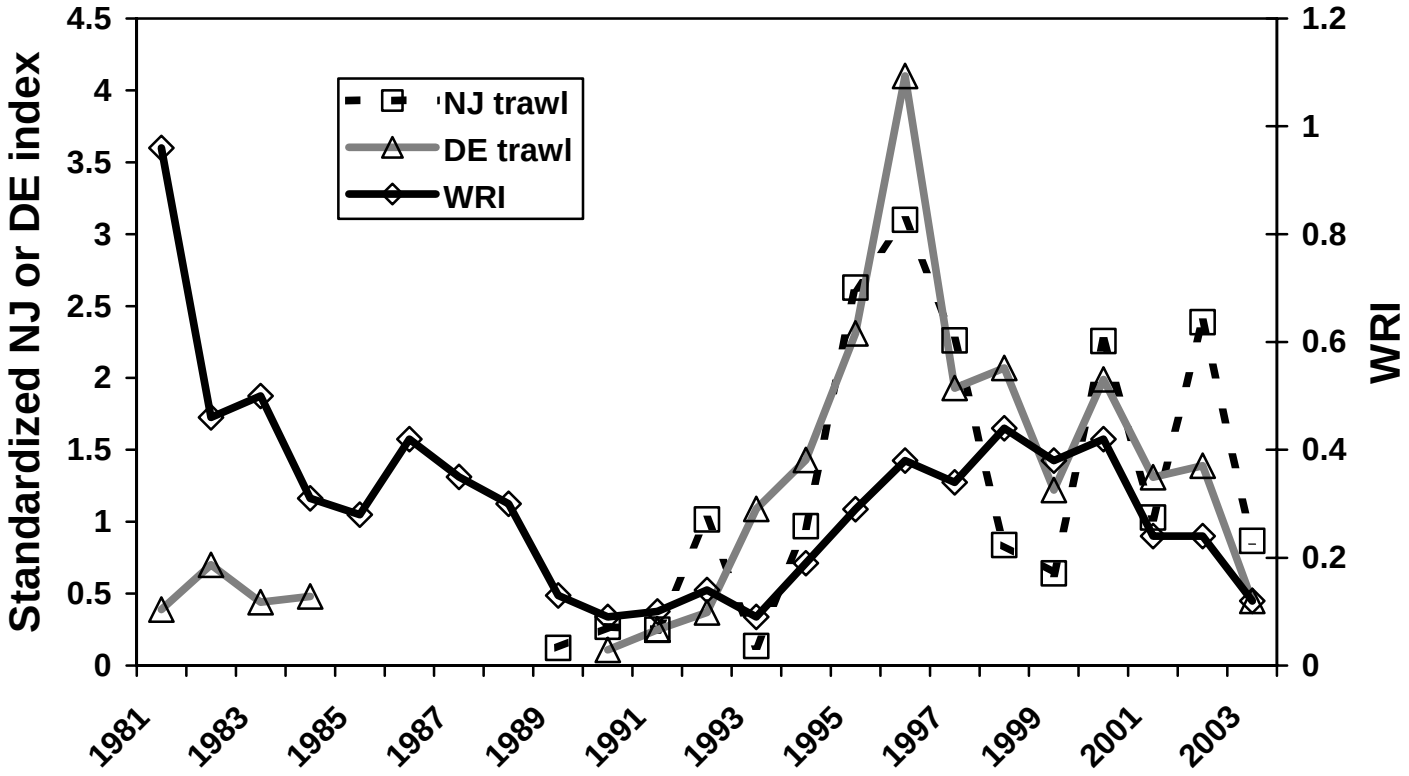


**Figure 3**. Estimated WRI and New Jersey and Delaware trawl survey catchability versus converged VPA biomass. Delaware estimates have been divided by 10 to place them on the figure.

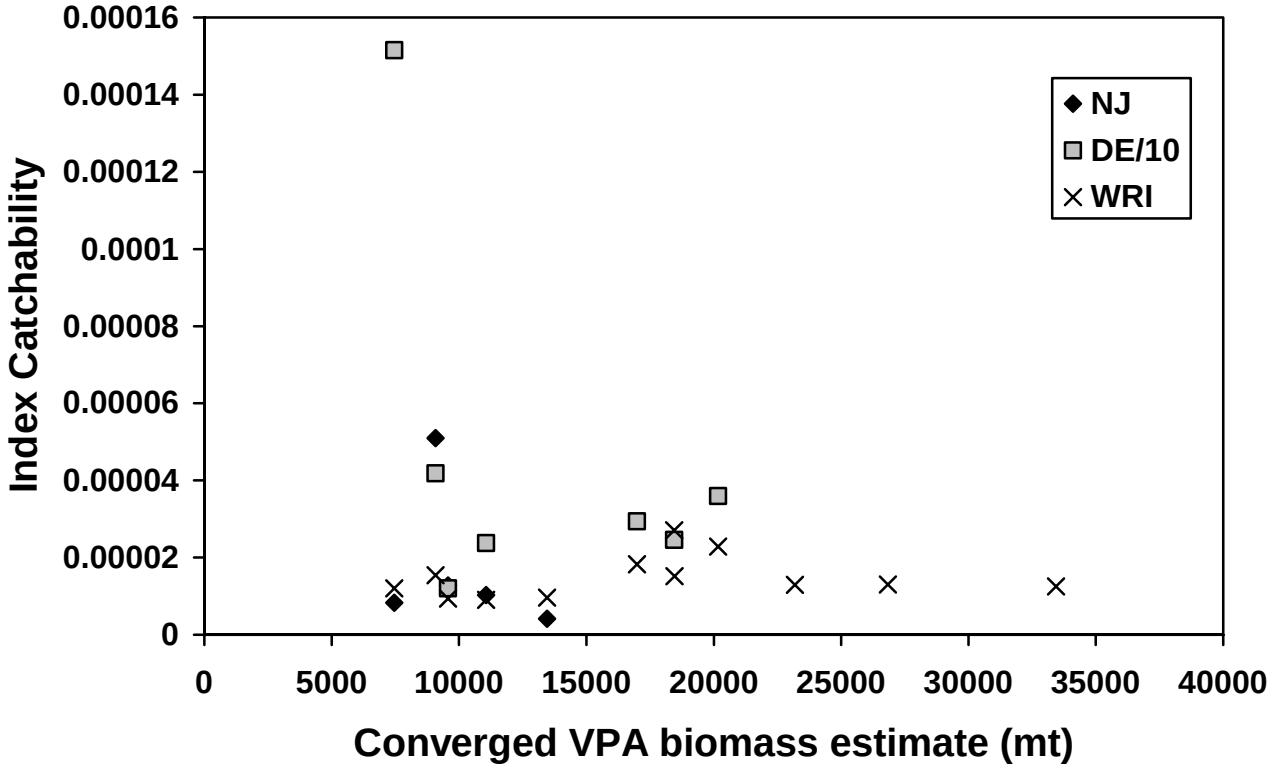


**Figure 4**. Mean weight at age of 1-5 year-old weakfish in the VPA catch-at-age matrix.

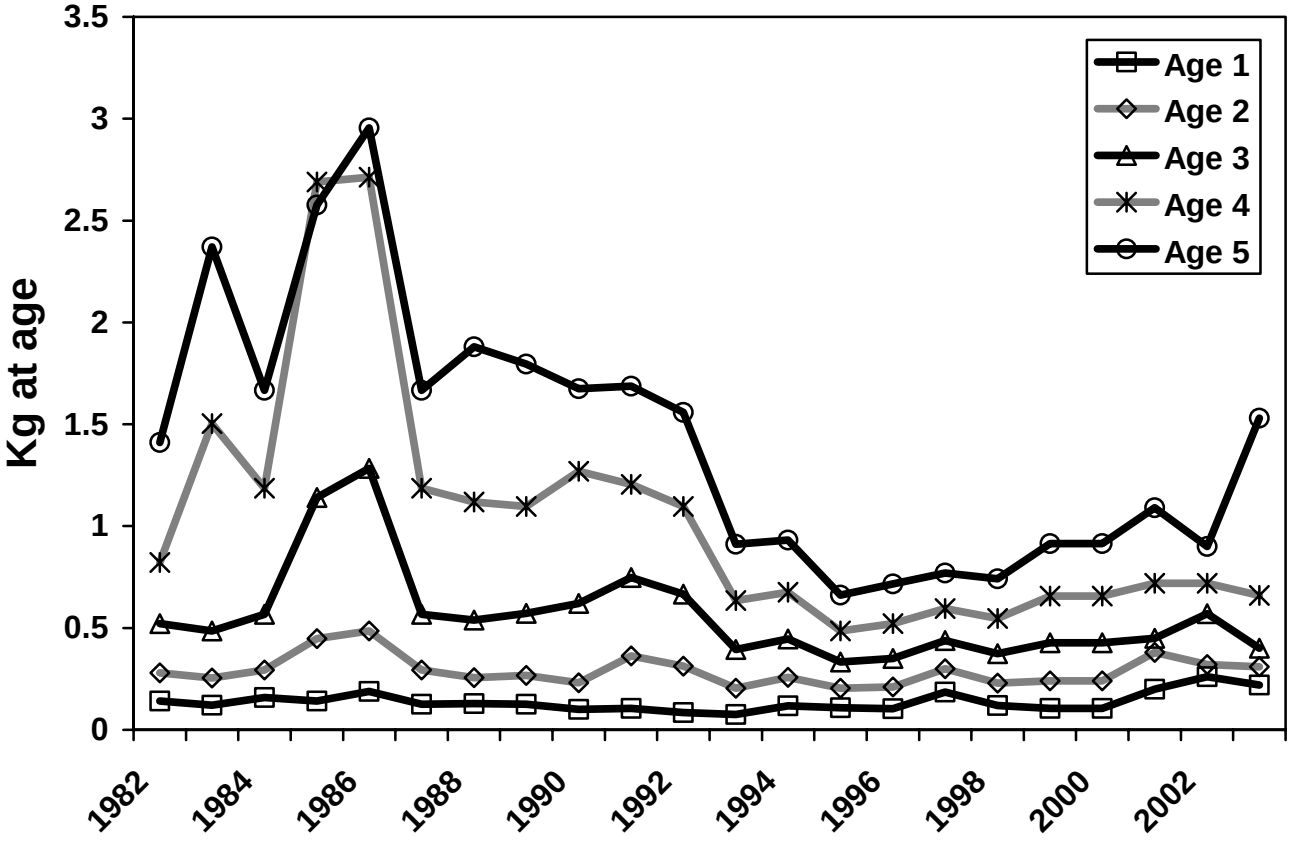


**Figure 5**. Delaware trawl survey Quality Proportional Stock Density (PSD Quality +). This index equals number of 340 mm+ weakfish divided by number that are 210 mm+ and indicates the proportion of weakfish of interest to anglers.

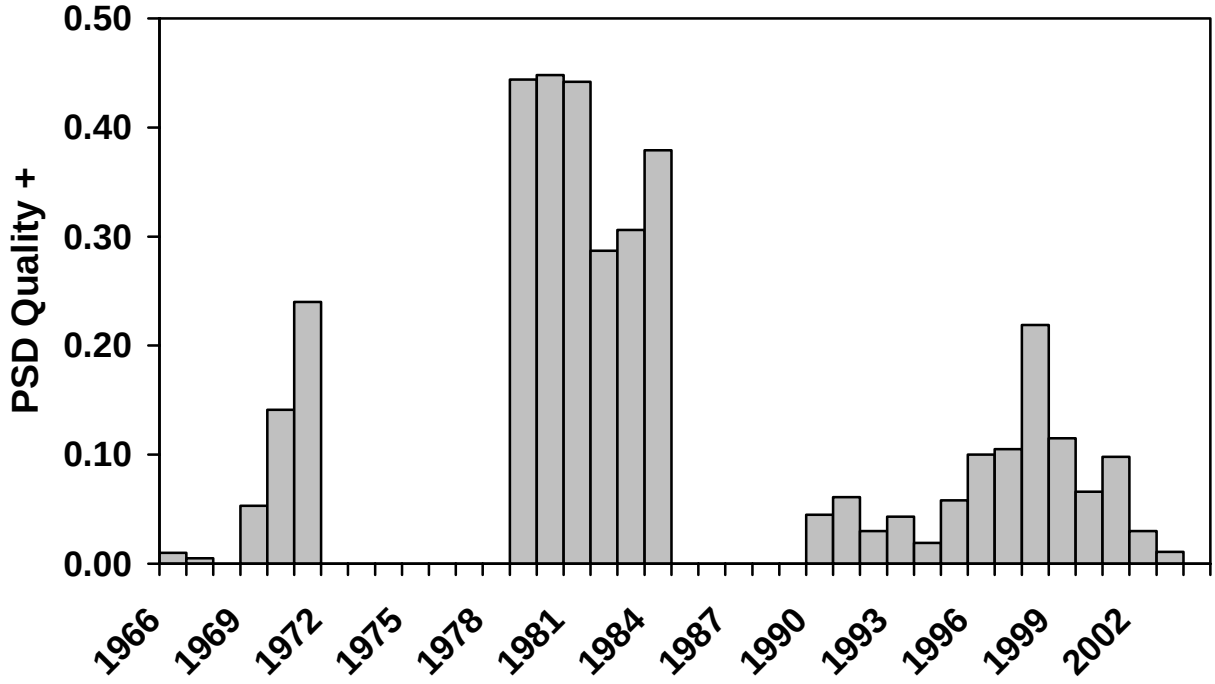


**Figure 6**. Striped bass biomass indicators along the Atlantic Coast.
Age 2+ biomass was estimated by ADAPT VPA (A. Sharov, MDDNR, personal communication). Egg presence-absence is the proportion of plankton tows with eggs in Chesapeake Bay spawning rivers and is a long-term indicator of mature female biomass (Uphoff 1997).

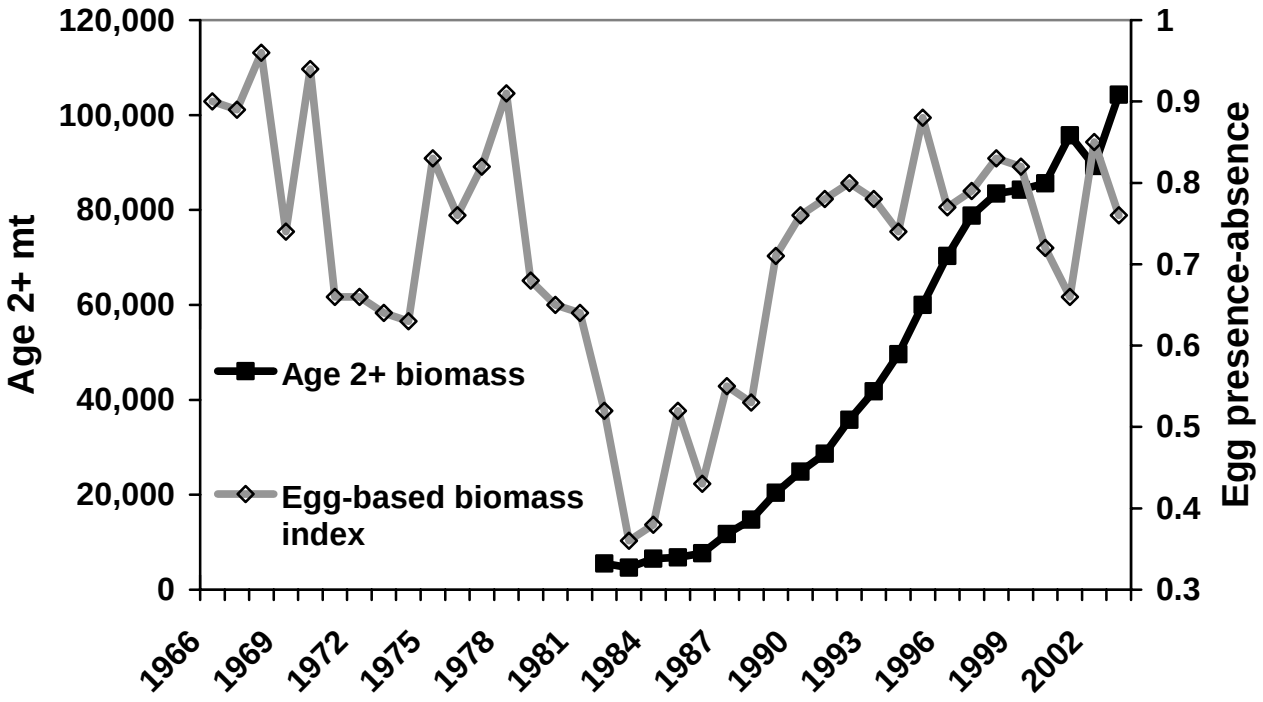


**Figure 7**. Z-transformed indices of relative abundance of age 0 menhaden in Maryland, Virginia, and North Carolina. Methodologies and locations are summarized in Table 1. Indices for NC are based on the same survey, but different estimators of central tendency; GM = geometric mean and DLN is delta log-normal. A value of zero indicates average abundance for the available time-series.

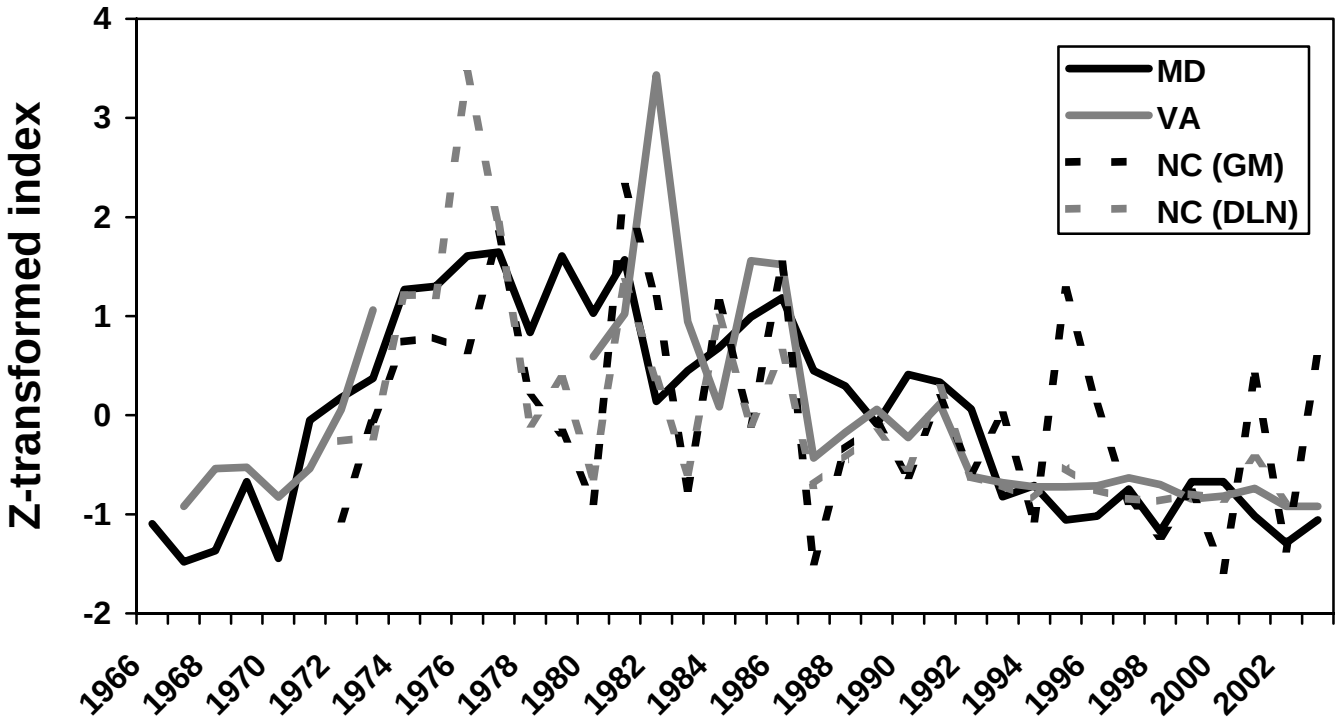


**Figure 8**. Z-transformed indices of relative abundance of age 0 menhaden in Delaware Bay. Methodologies and locations are summarized in Table 1. A value of zero indicates average abundance for the available time-series.

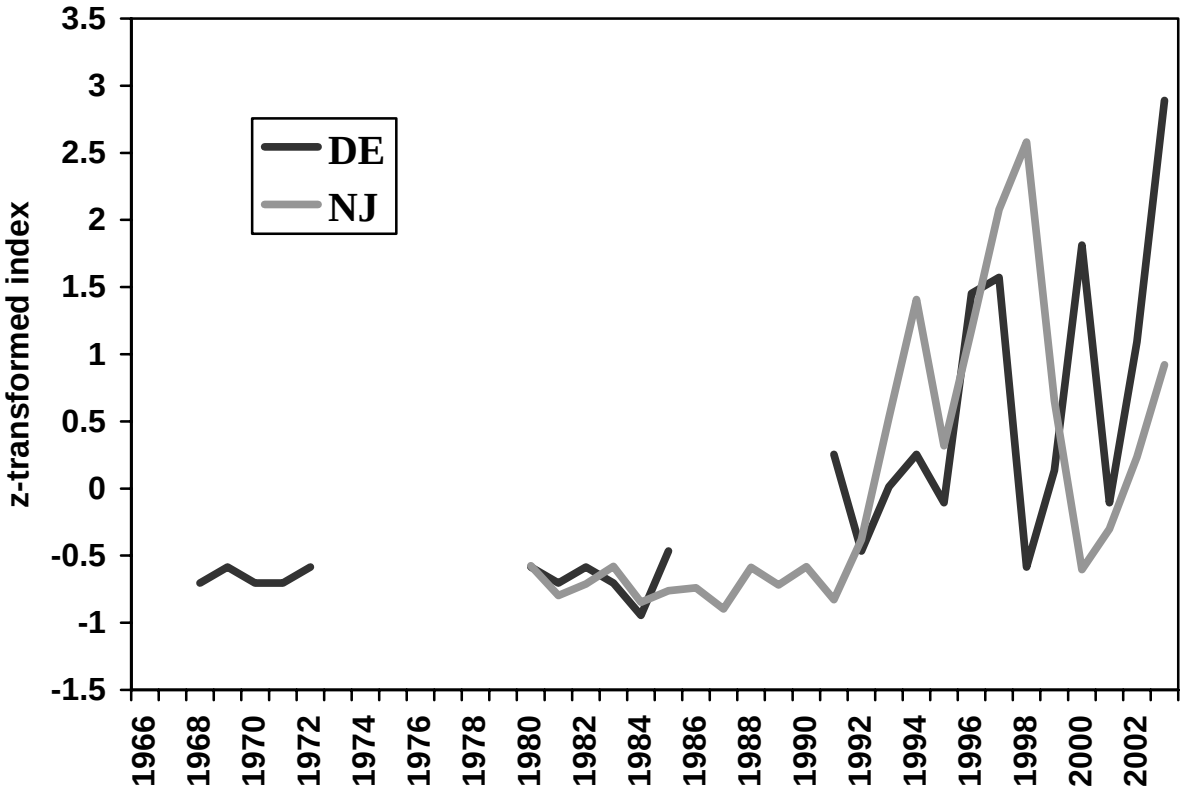


**Figure 9**. Estimated abundance of age 0 Atlantic menhaden along the Atlantic Coast (ASMFC 2004).

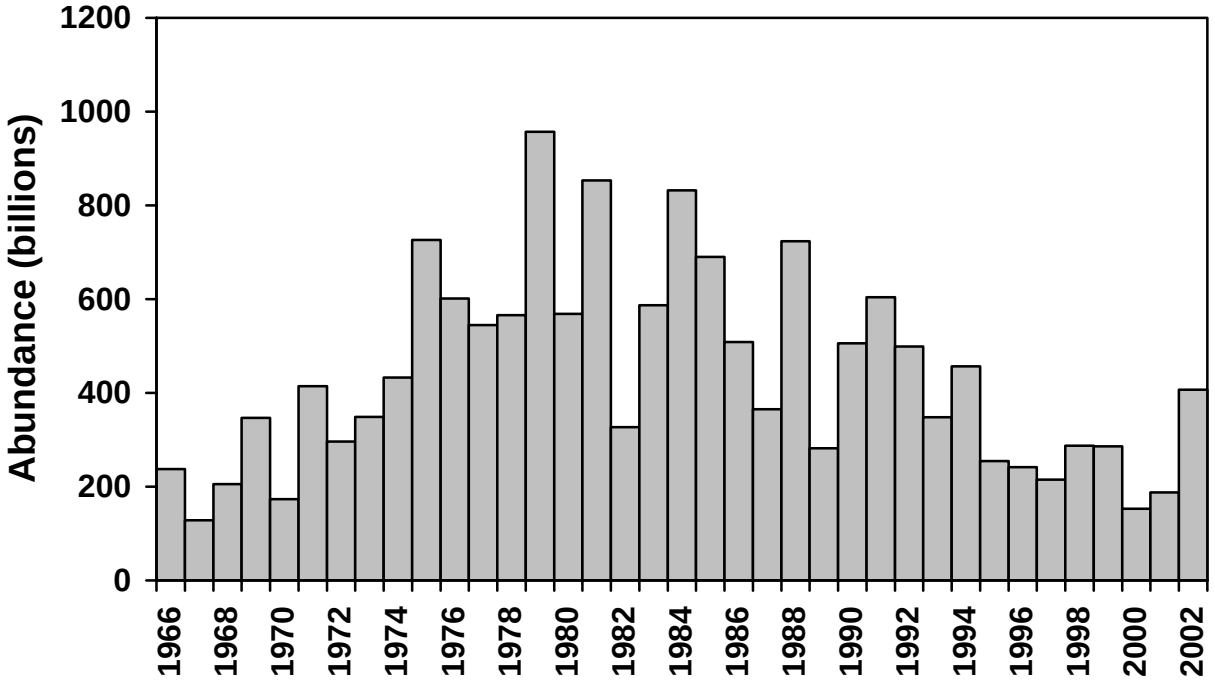


**Figure 10**. Z-transformed indices of relative abundance of spot in Maryland, Virginia, and North Carolina. Methodologies and locations are summarized in Table 1. Indices T = trawl and S = seine. A value of zero indicates average abundance for the available time-series.

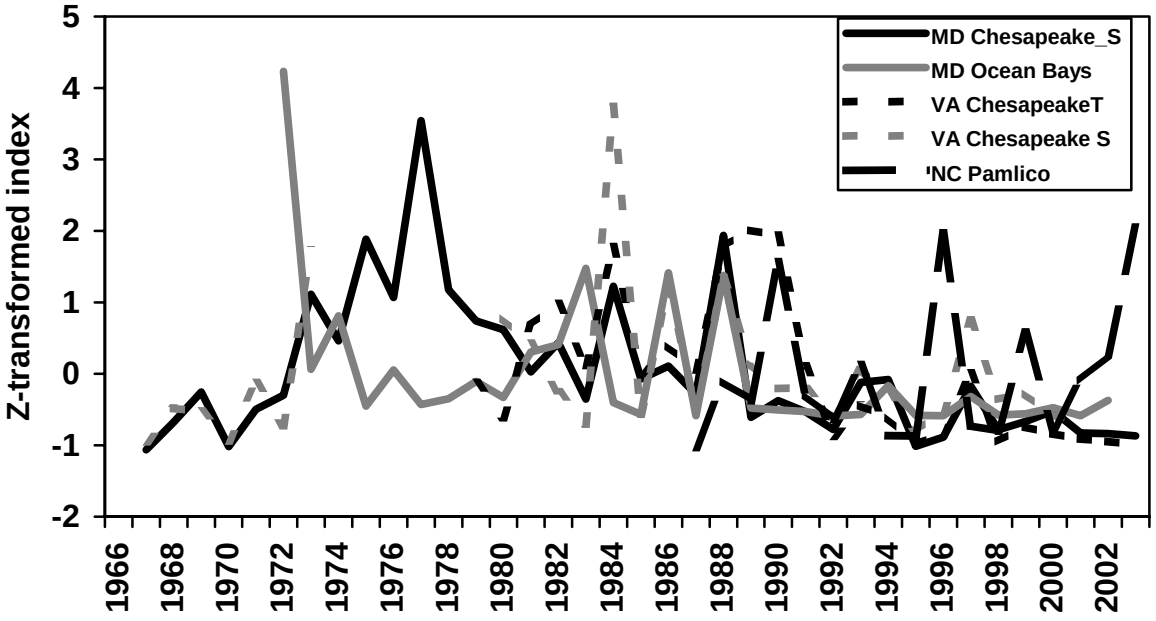


**Figure 11**. Z-transformed indices of relative abundance of spot in Delaware and New Jersey. Methodologies and locations are summarized in Table 1. Indices T = trawl and S = seine. A value of zero indicates average abundance for the available time-series.

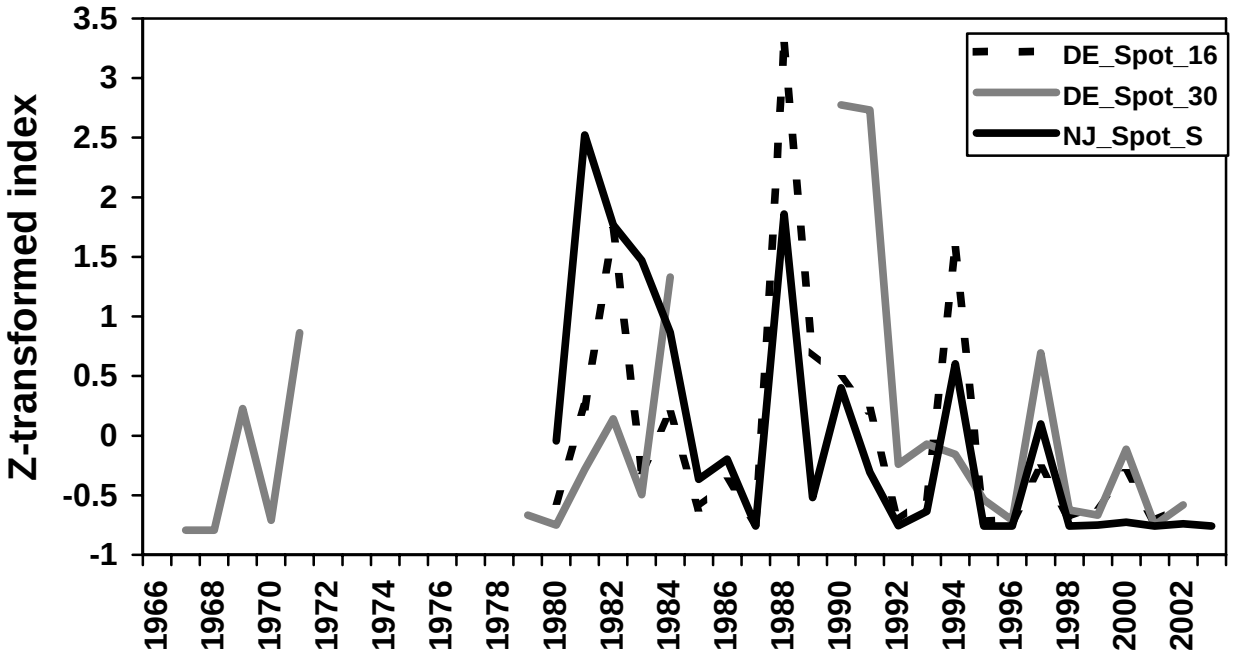


**Figure 12**. Z-transformed indices of relative abundance of bay anchovy in Maryland, Virginia, and North Carolina. Methodologies and locations are summarized in Table 1. Indices T = trawl and S = seine. A value of zero indicates average abundance for the available time-series.

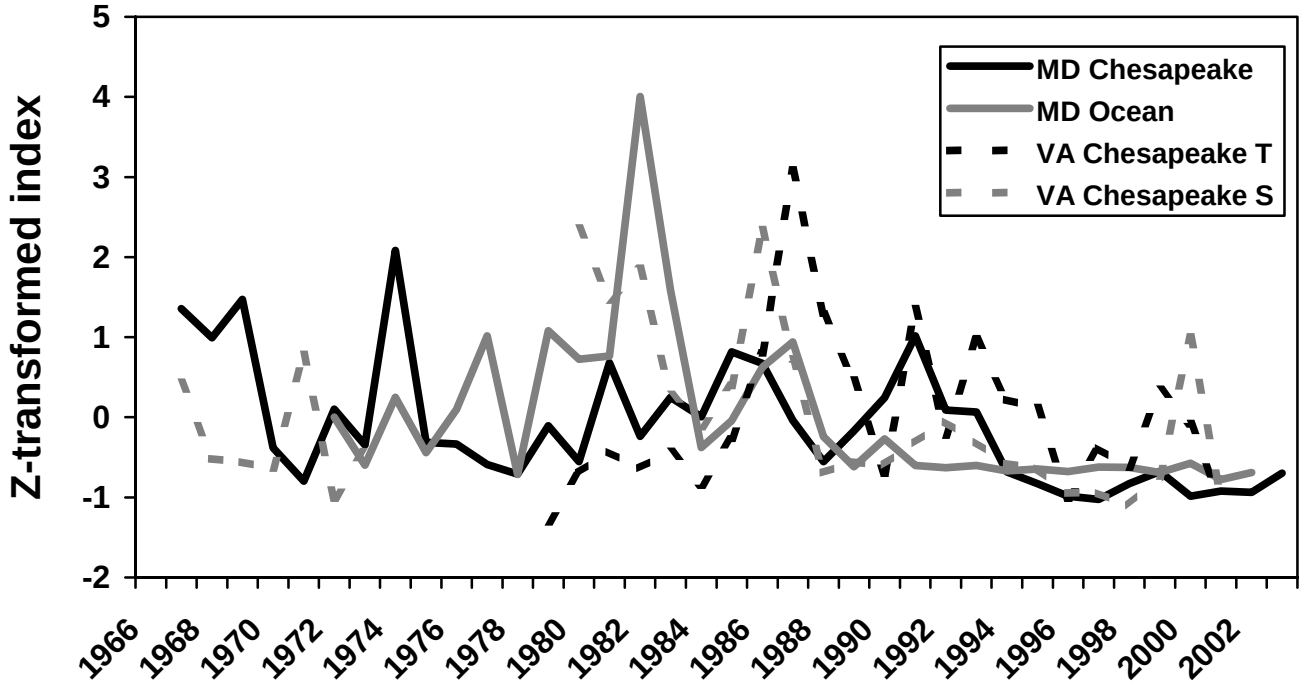


**Figure 13**. Z-transformed indices of relative abundance of bay anchovy in Delaware and New Jersey. Methodologies and locations are summarized in Table 1. Indices T = trawl and S = seine. A value of zero indicates average abundance for the available time-series.

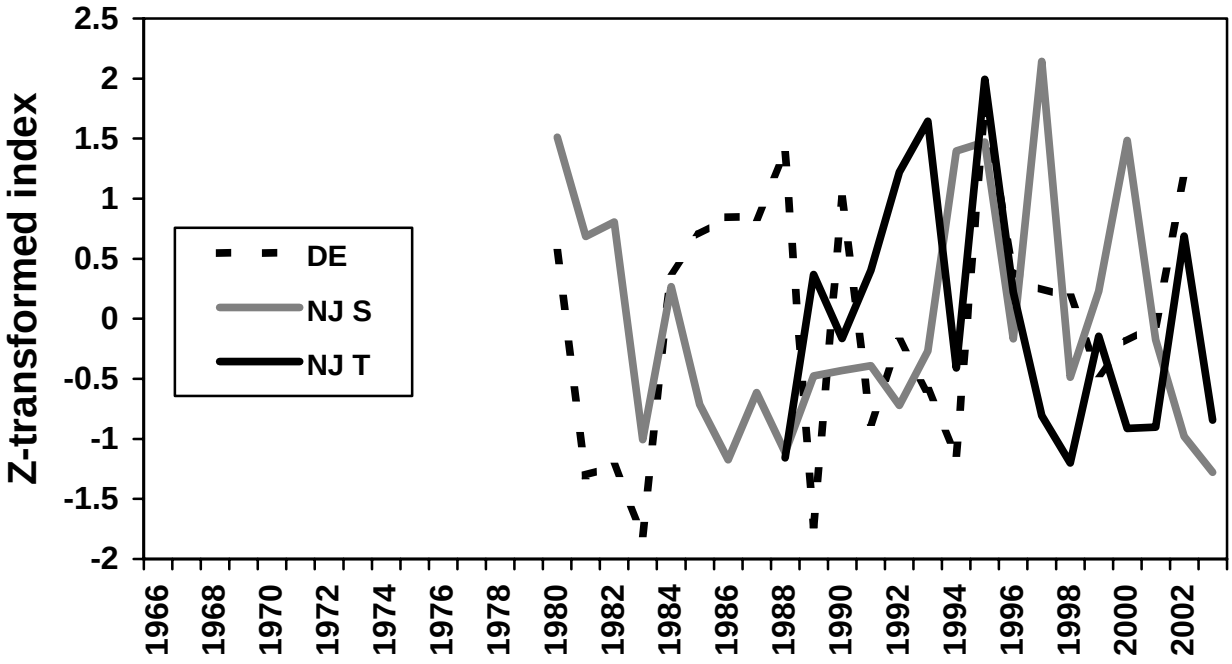


**Figure 14**. Predicted and observed PSD Q+ weakfish size quality index from multiple regression of age 0 menhaden abundance and a striped bass biomass index.

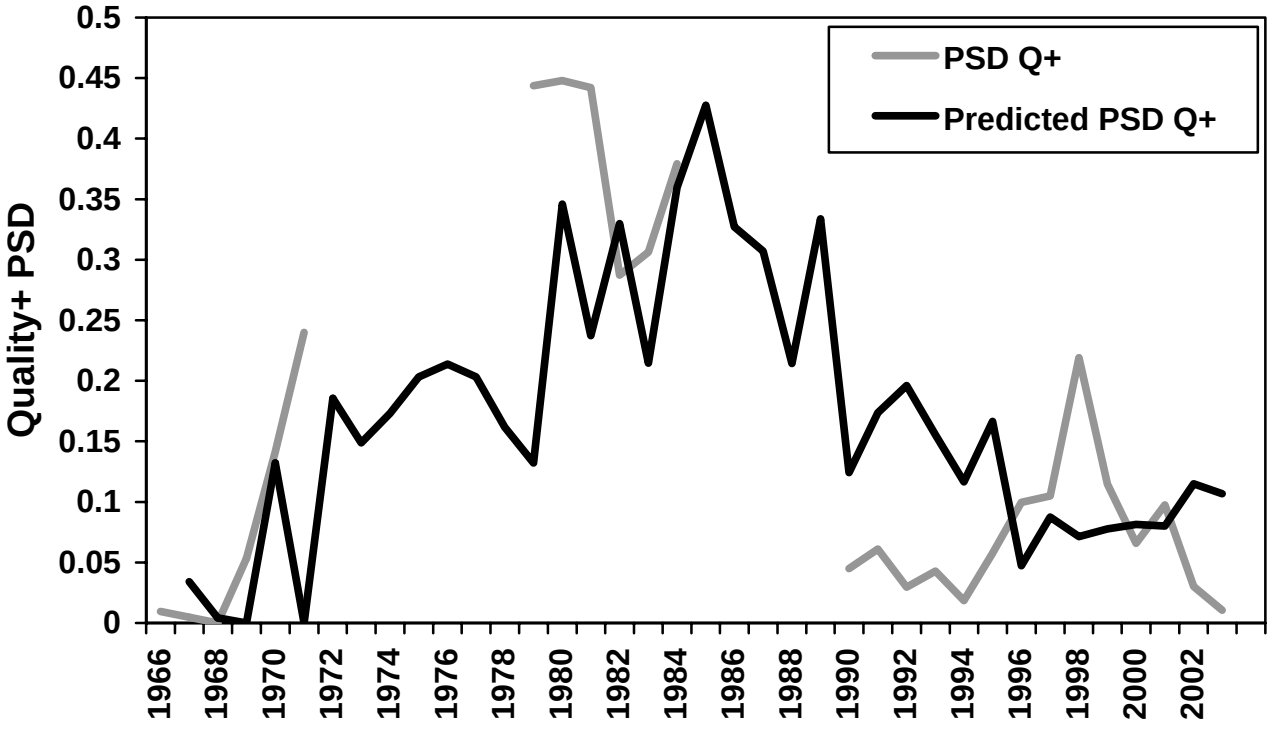


**Figure 15**. Weakfish catch per trip (includes number harvested and released) index (WRI) versus age 2+ striped bass biomass. Different stanzas are represented by different symbols.

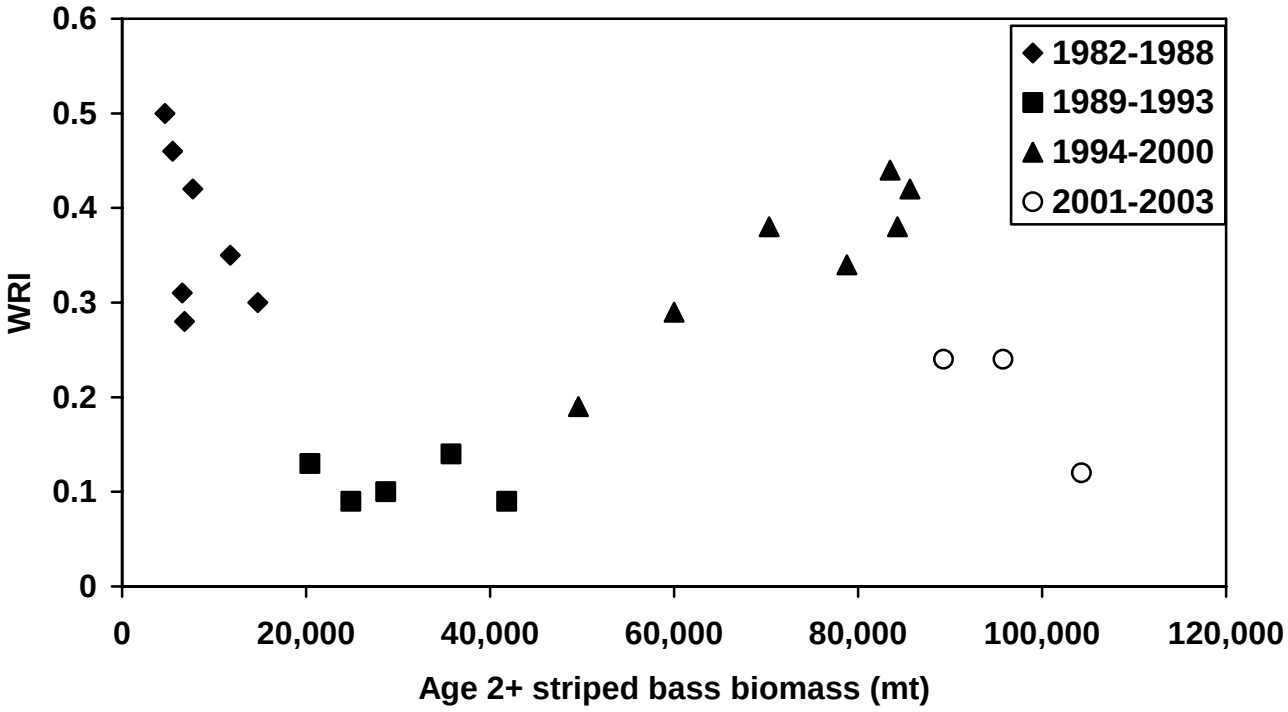


**Figure 16**. Weakfish biomass indices for DE and NJ trawl surveys versus age 2+ striped bass biomass. Indices are Z-transformed + 1 values. Stanzas in Figure 15 (WRI and striped bass) are maintained and represented by different symbols. Solid symbols represent DE and unfilled symbols indicate NJ.

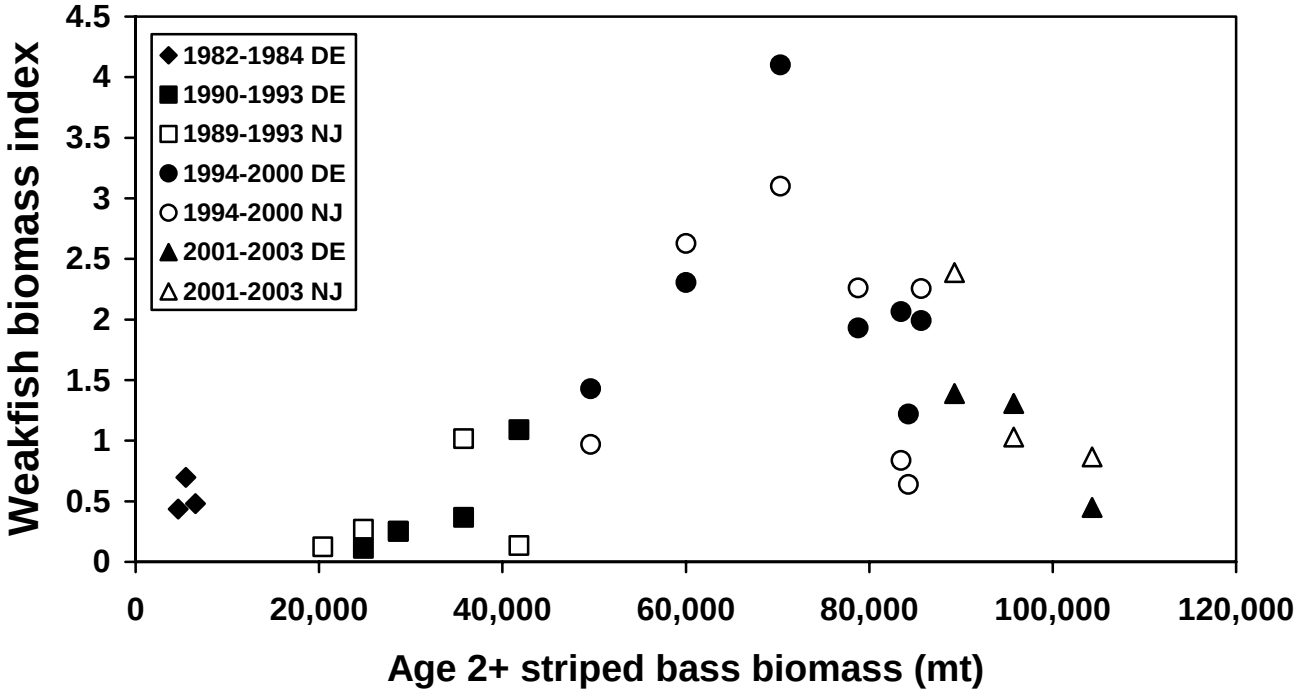


**Figure 17**. Atlantic Coast commercial landings of weakfish plotted against striped bass landings during 1950-2003. Decades are identified by different symbols; 1990s included 2000-2003. Predicted landings estimated by categorical regression are indicated by solid lines.

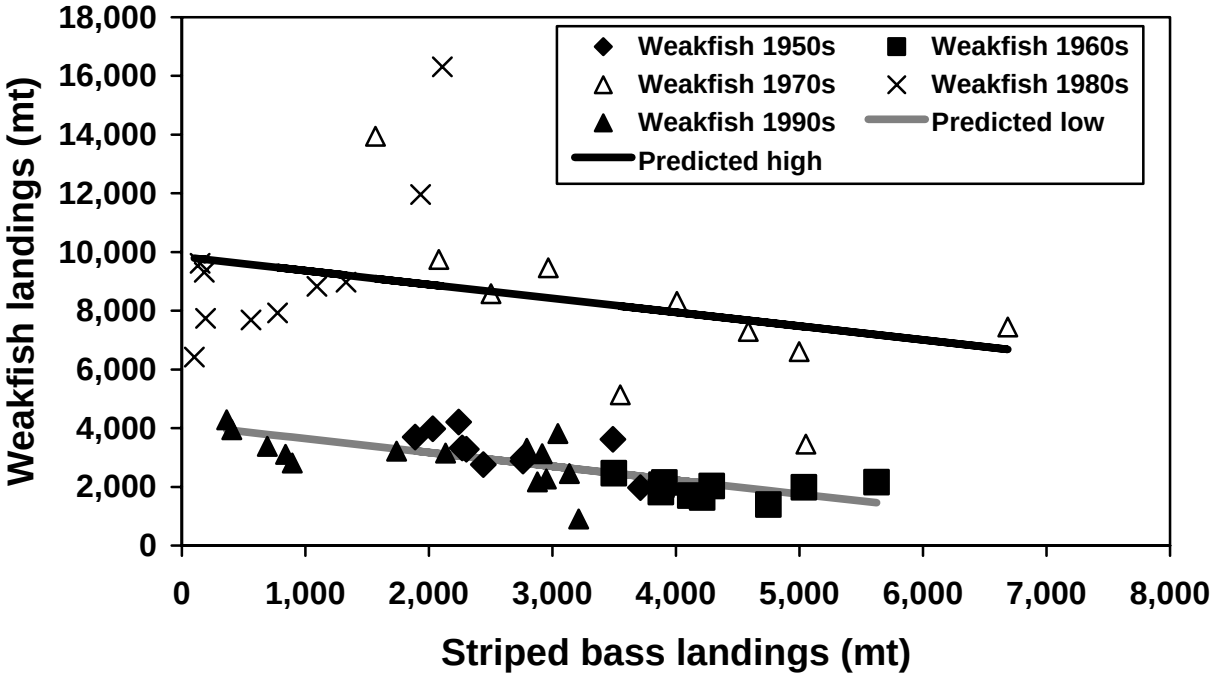


**Figure 18**. Observed and predicted weakfish landings from categorical regression of bass egg index and time period category.

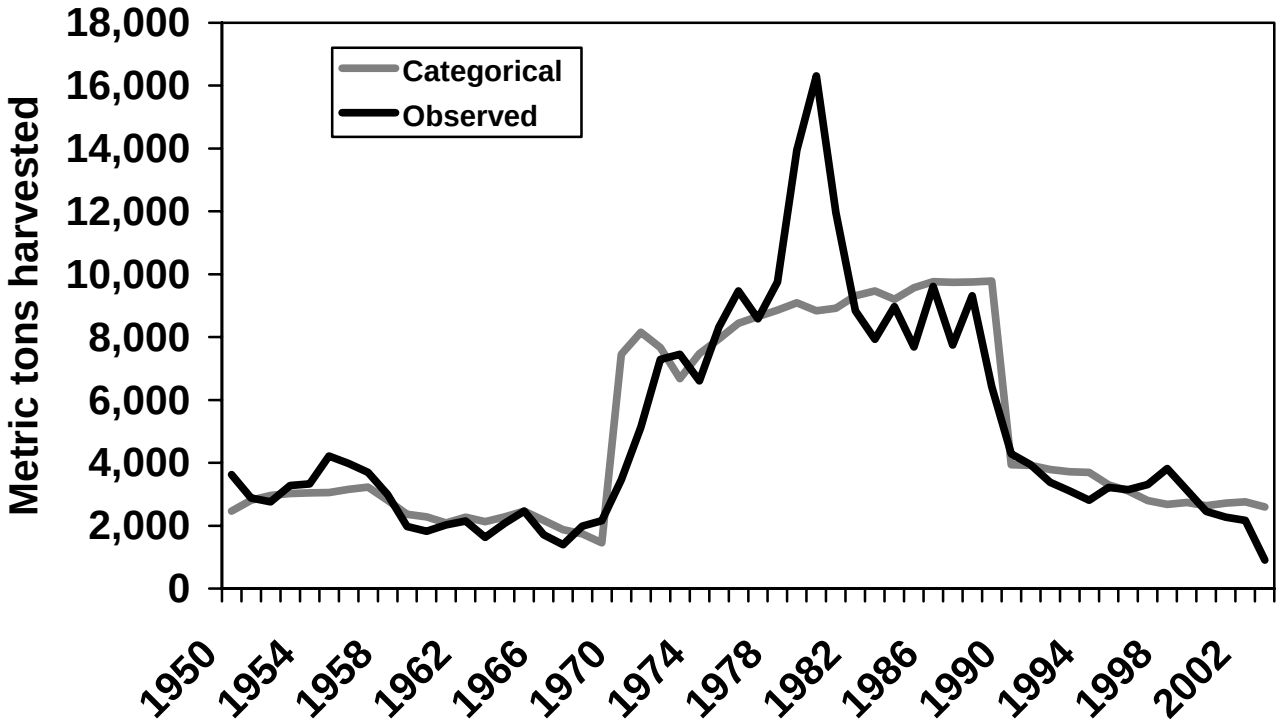


**Figure 19**. Observed and predicted weakfish landings from multiple regressions of bass egg index and menhaden abundance estimates or menhaden juvenile index.

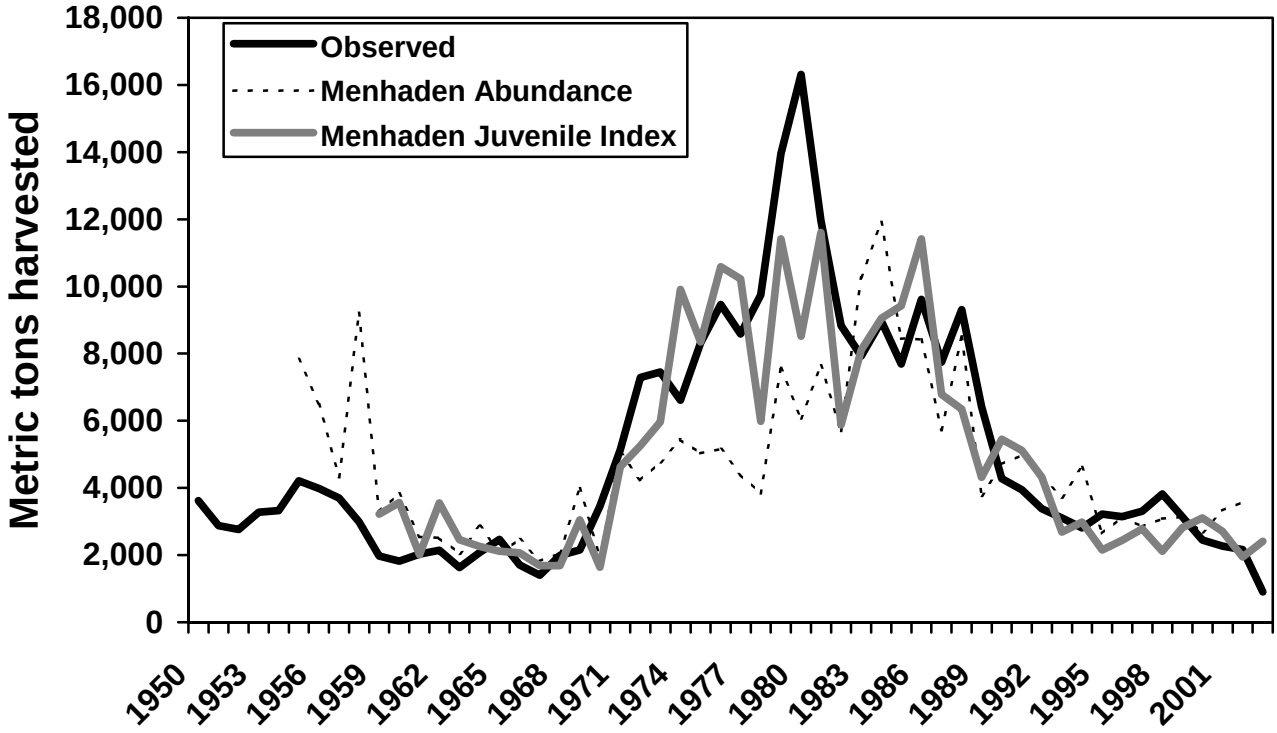


**Figure 20**. Trends in $M_{vpa}$.

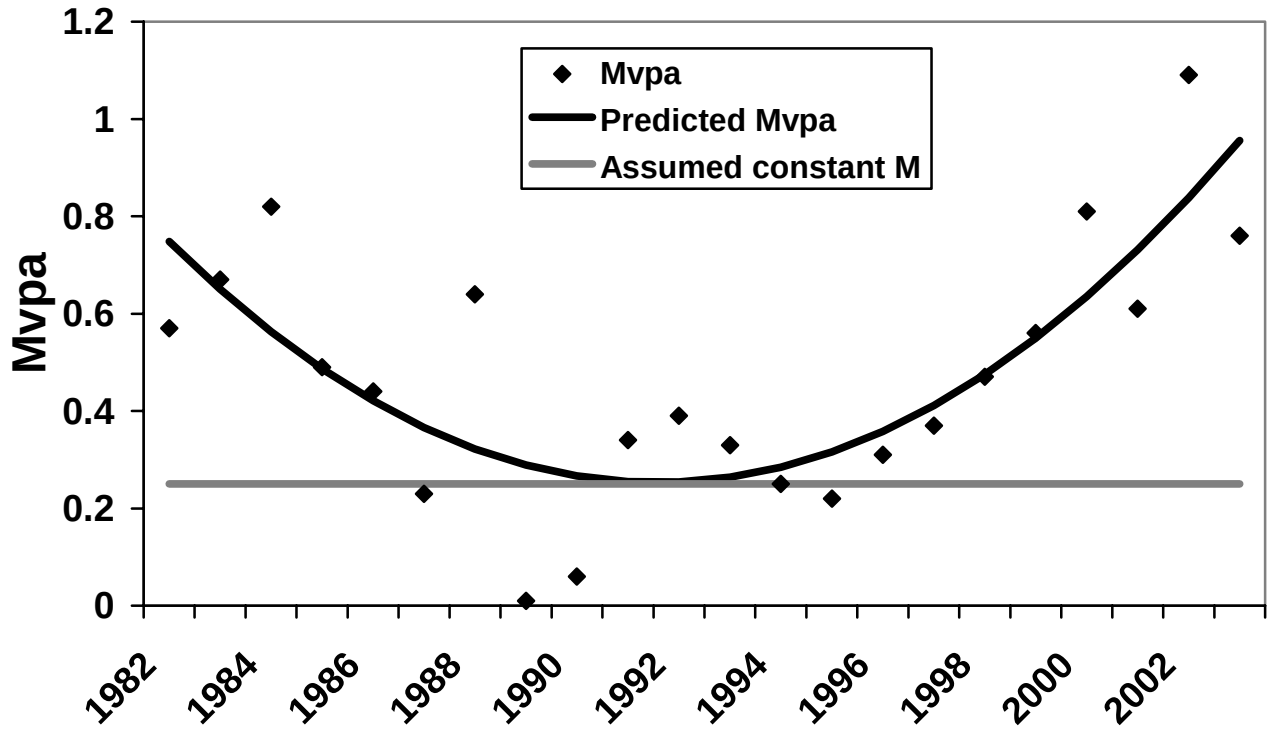


**Figure 21**. Observed and weakfish biomass indices estimated by logistic striped bass-weakfish predator-prey model.

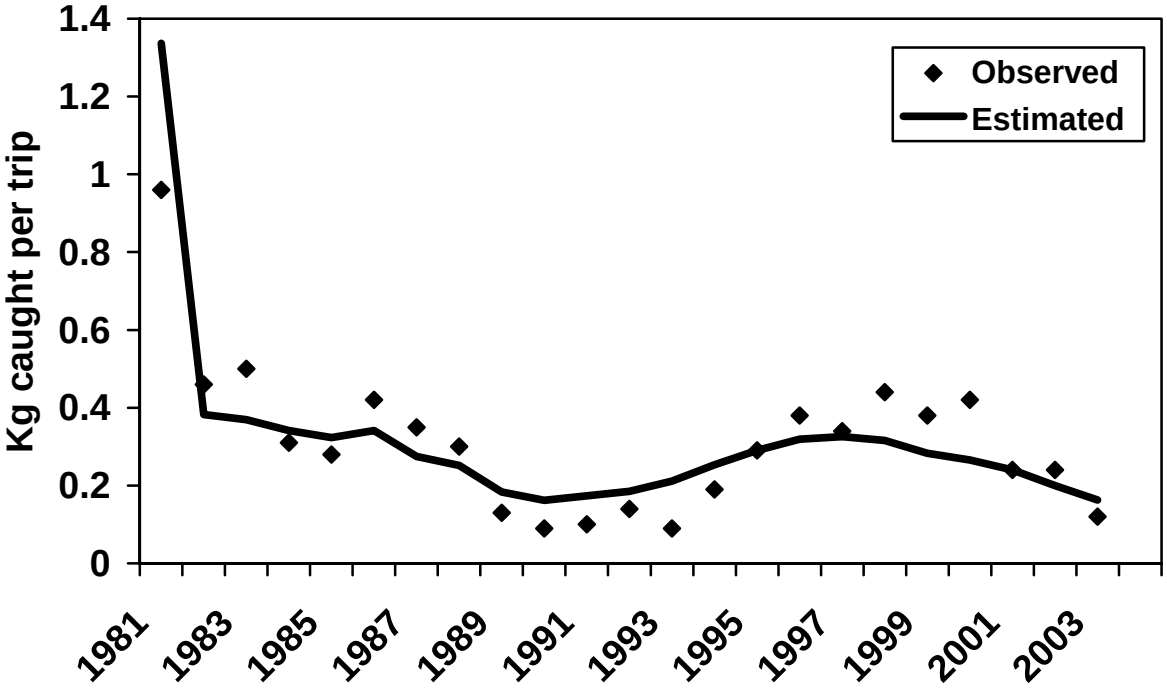


**Figure 22**. Annual instantaneous mortality rates due to fishing (F), striped bass competition and predation (Mb), F+Mb (Z), and biomass estimated from the logistic predator-prey model.

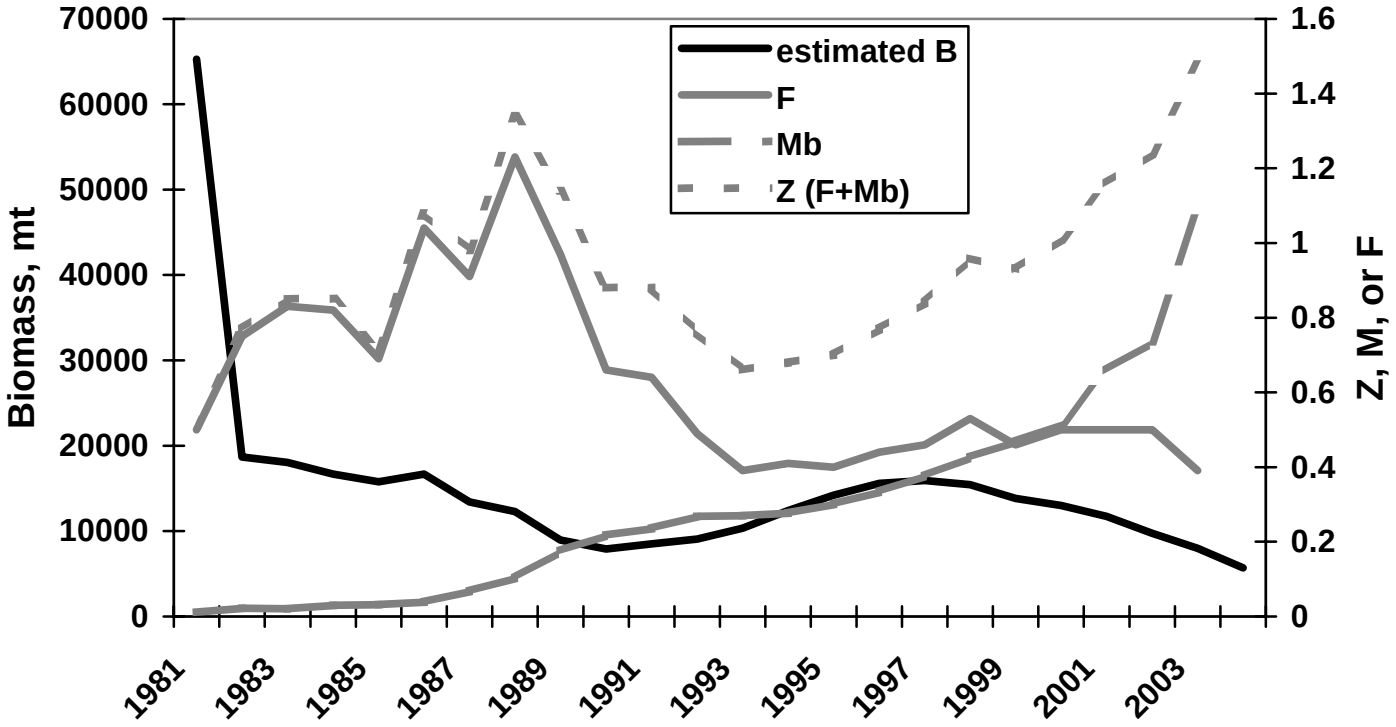


**Figure 23**. Surplus production estimated from the logistic predator-prey model with and without (traditional) accounting for striped bass predation and competition.

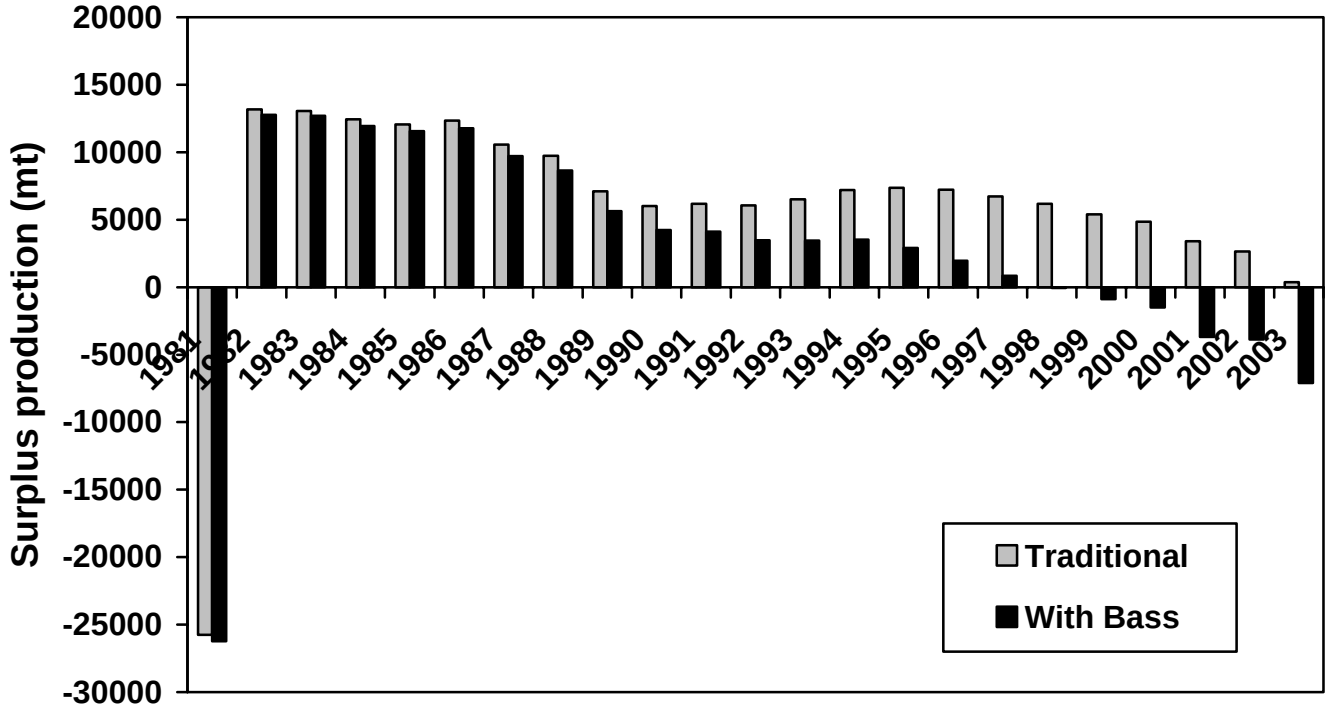


**Figure 24**. Surplus production calculated with and without (traditional) striped bass associated losses plotted against estimates of F during 1982-2003 from the logistic predator-prey model. Points from 1981 were treated as outliers and omitted from this plot.

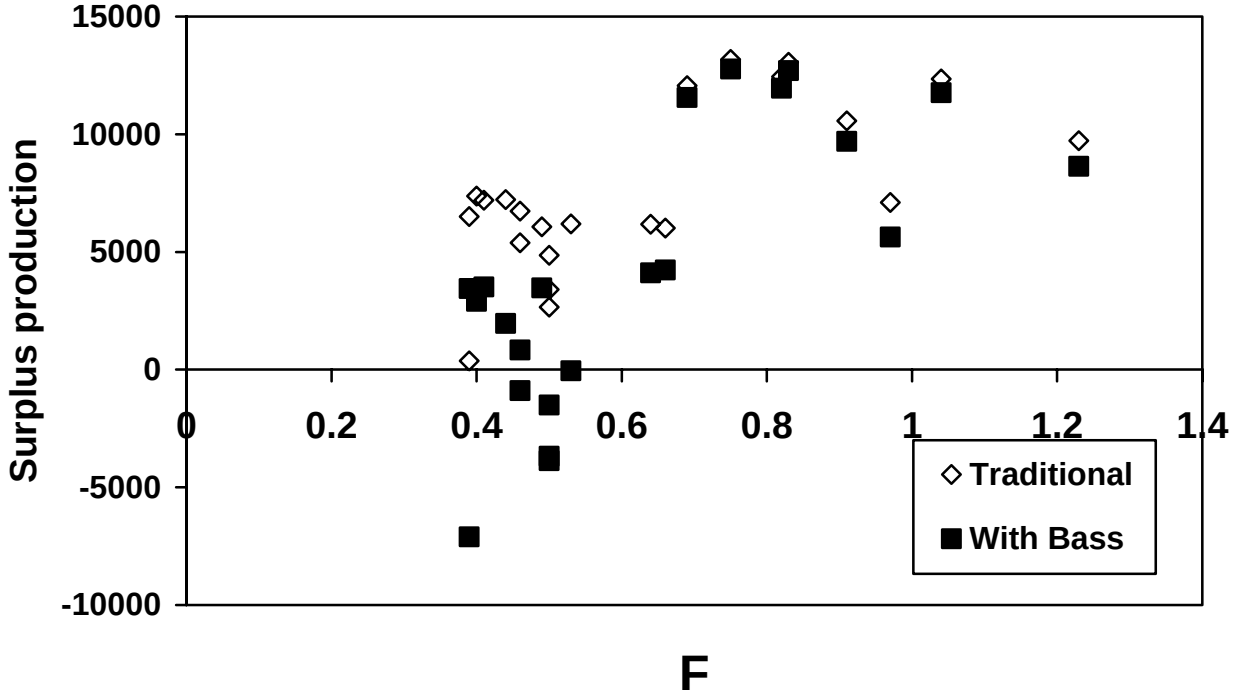


**Figure 25**. Surplus production calculated with and without (traditional) striped bass associated losses plotted against estimates of Mb during 1982-2003 from the logistic predator-prey model. Points from 1981 were treated as outliers and omitted from this plot.

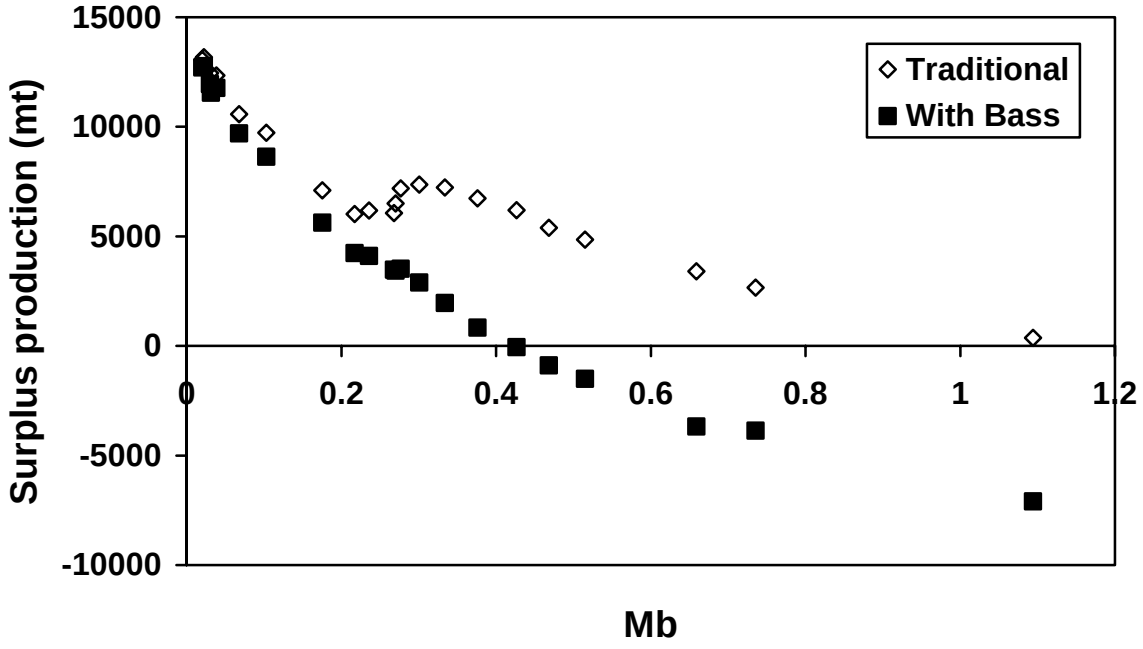


**Figure 26**. Fit of Schaefer and logistic Steele and Henderson (predator-prey) models to the WRI time-series

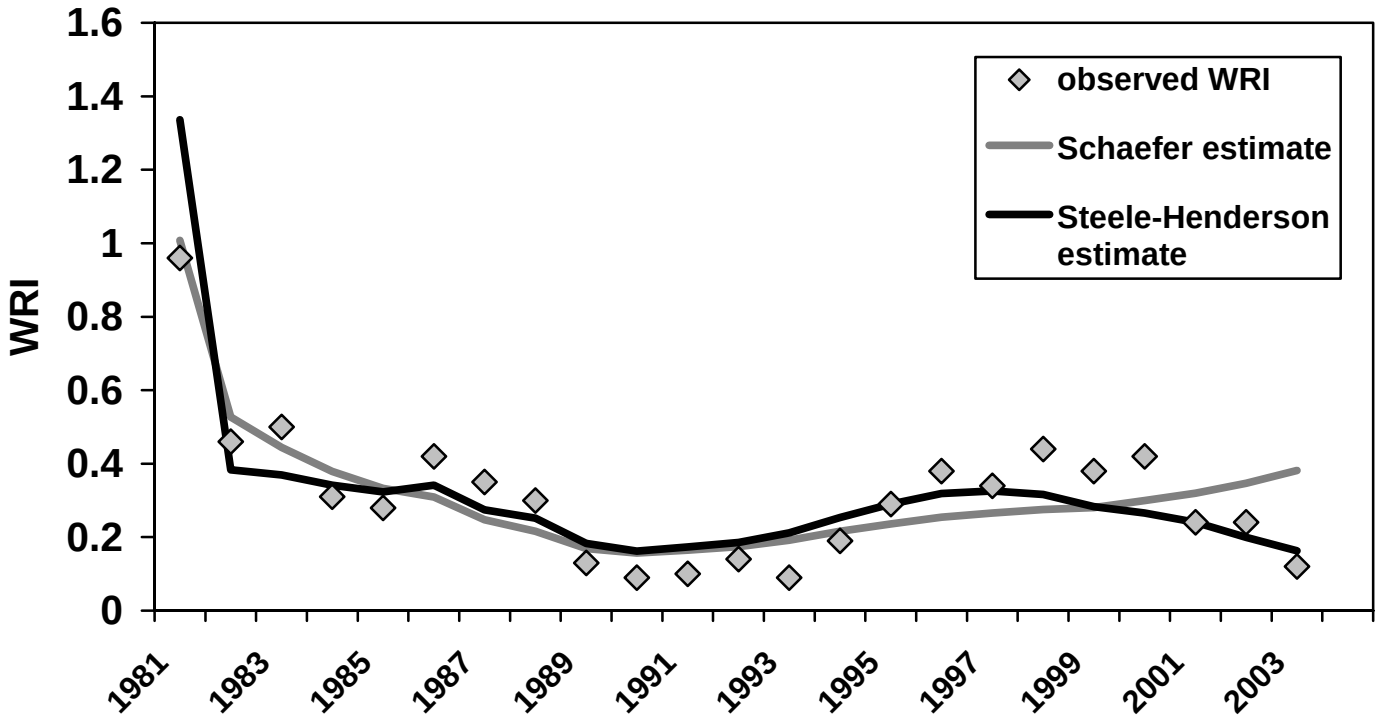


**Figure 27**. Observed and predicted indices from sensitivity analysis of time-series of the logistic predator-prey model. Original data – 1981-2003. 1-3 years removed from beginning (start) and end; 1981 fixed indicates a value was set to initiate time-series.

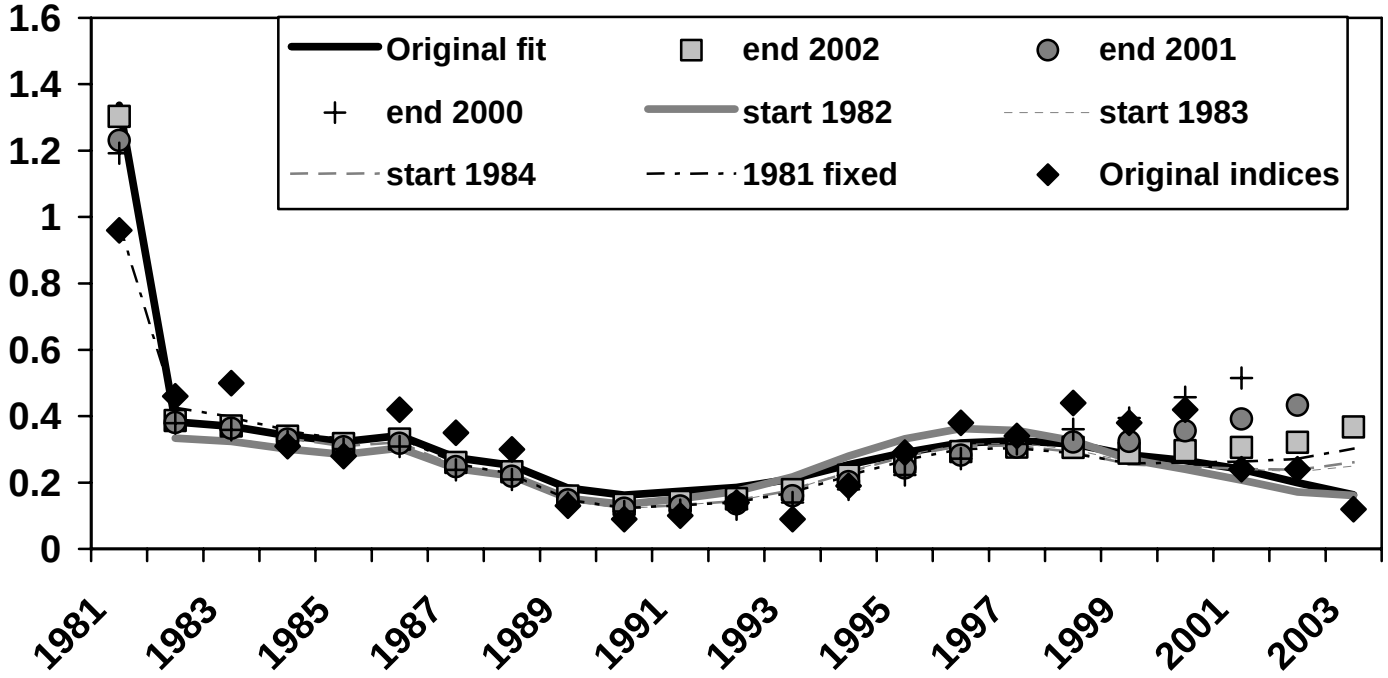


**Figure 28**. Logistic predator-prey model predicted weakfish biomass consumed per unit of striped bass biomass plotted against weakfish biomass (striped bass functional response) for two time-series. Intersections of predator-prey parameters c and A are indicated for each time-series by open symbols.

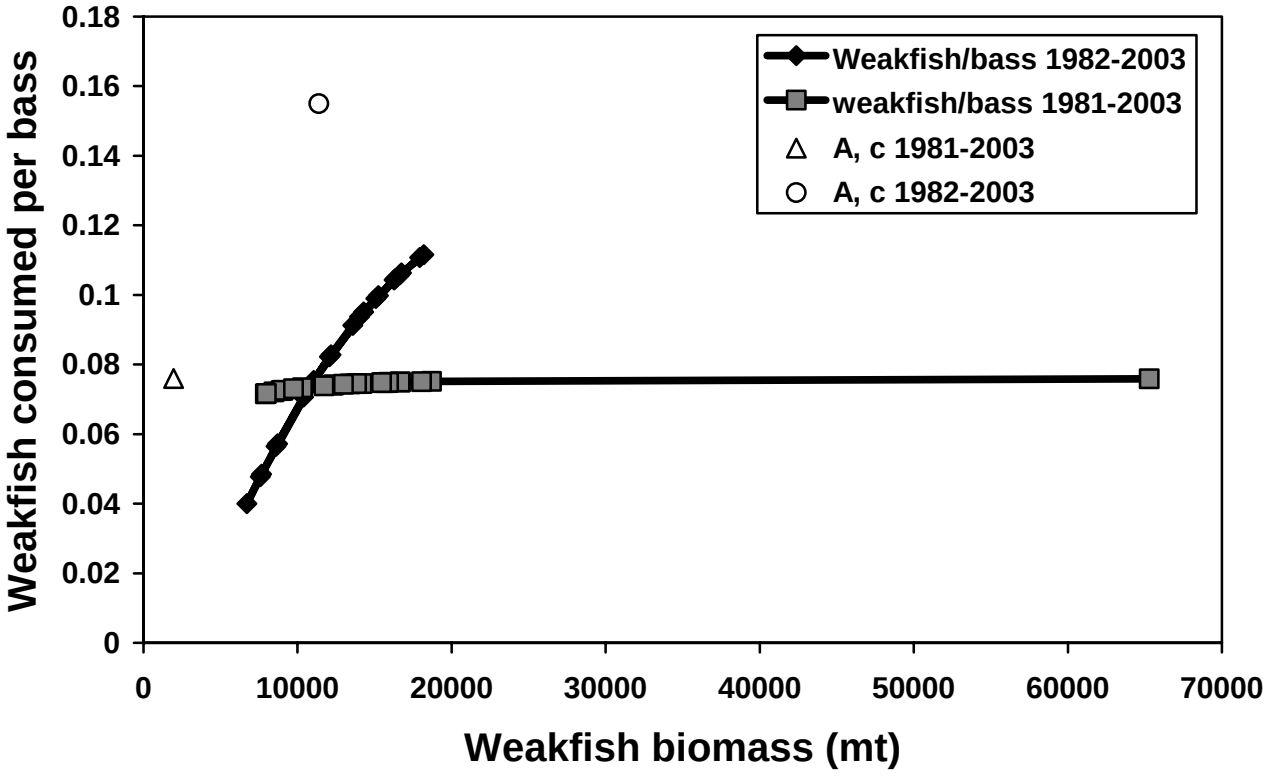


**Figure 29**. F estimated from rescaled VPA, Schaefer, and logistic Steele and Henderson predator-prey models with the WRI as their basis.

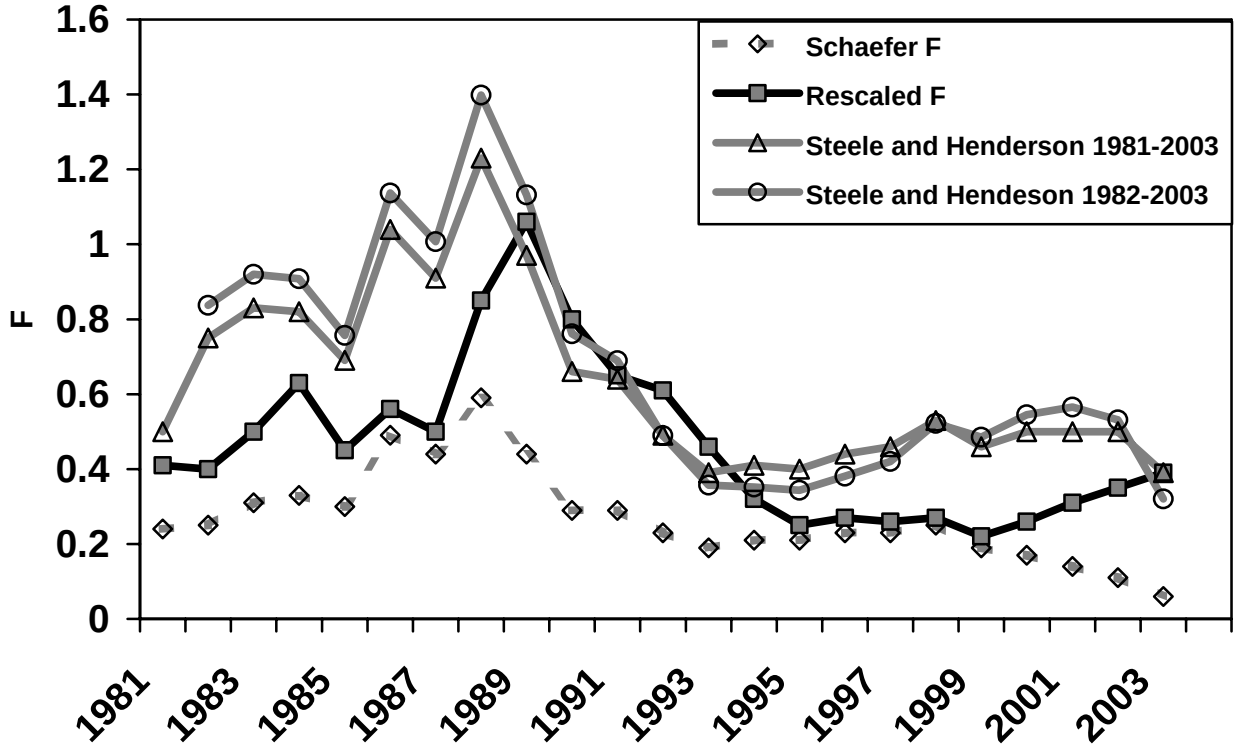


**Figure 30**. Estimates of Mb from the logistic weakfish-bass predator-prey model applied to two time-series.

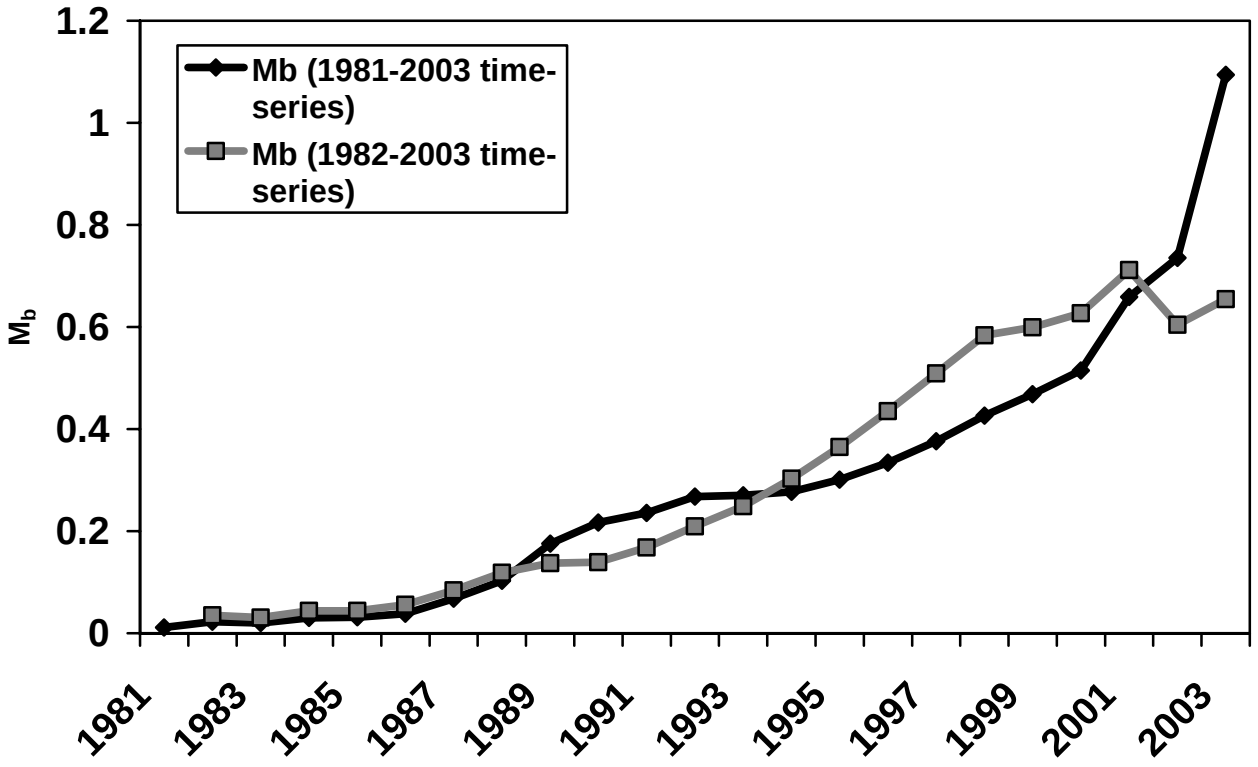


**Figure 31**. Estimates of Z from ADAPT and from logistic striped bass-weakfish predator-prey models (Steele and Henderson model). Predator-prey model does not include M from sources other than striped bass.

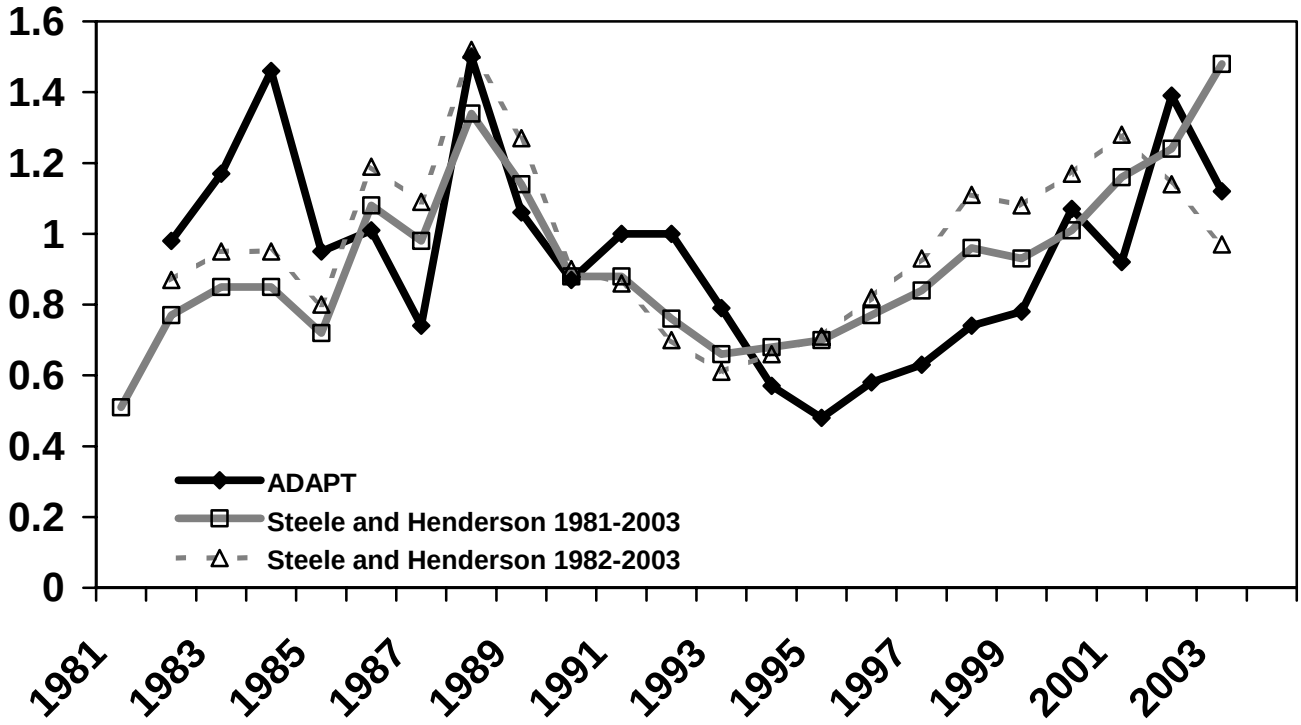


**Figure 32**. Logistic predator-prey model biomass estimates based on WRI. Figure omits 1981 estimates.

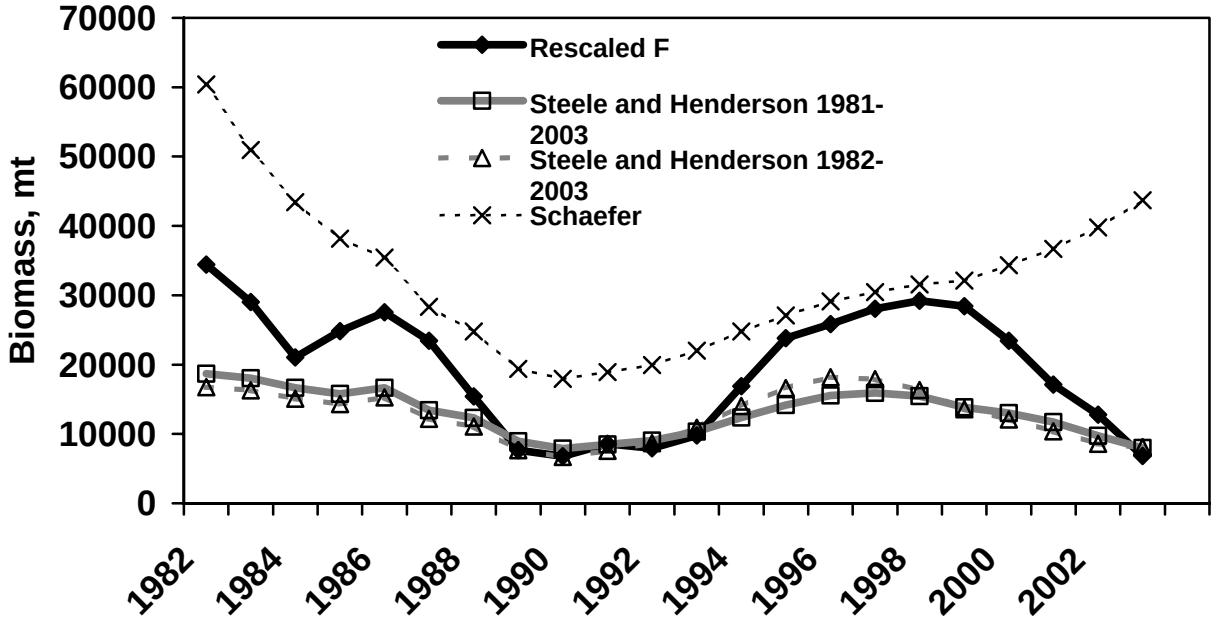


**Figure 33**. Trends in biomass of weakfish and other candidate alternative predator-competitors for the logistic predator-prey model.

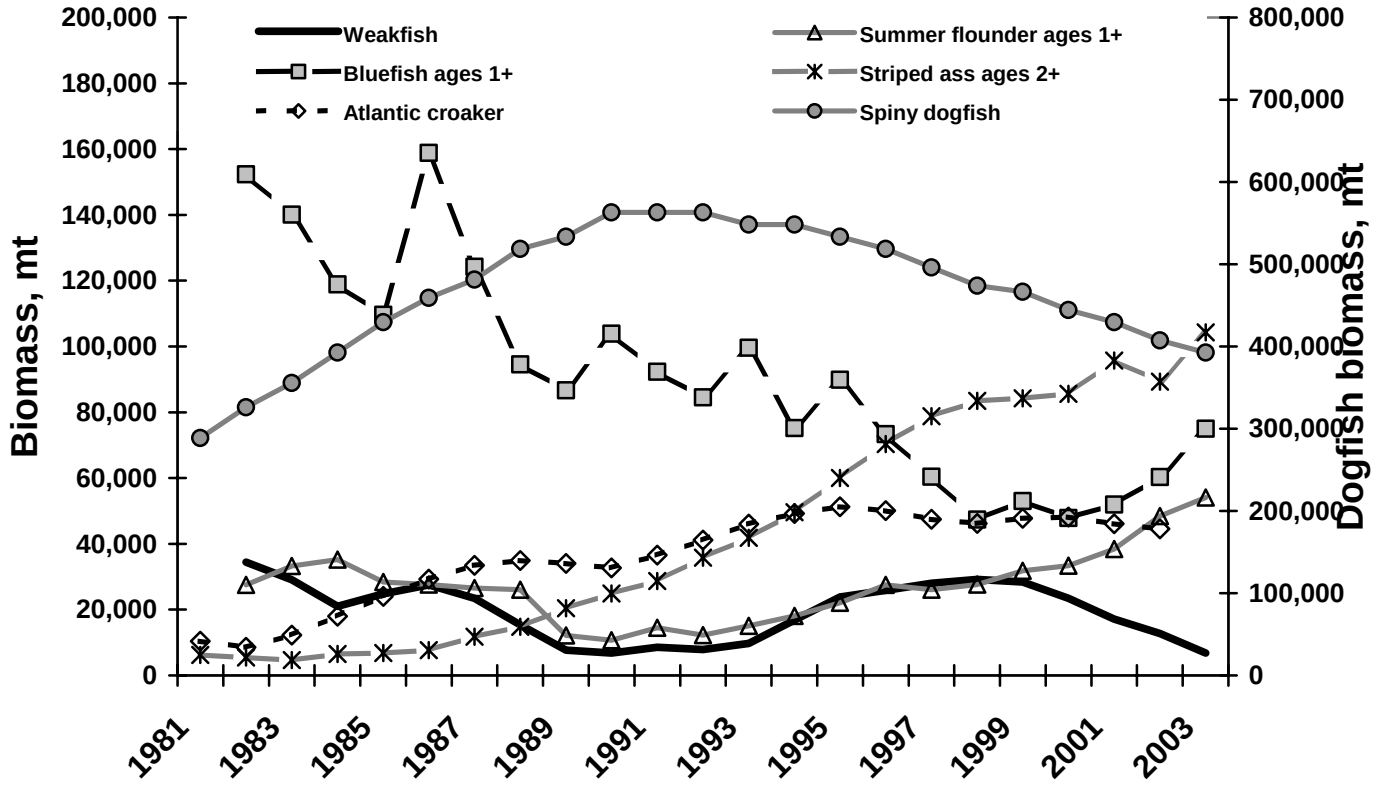


**Figure 34**. Weakfish biomass predicted from an Atlantic croaker- weakfish logistic predator-prey model and "observed" weakfish biomass from rescaled relative F analysis. Both are based on the same MRFSS catch per effort index for weakfish.

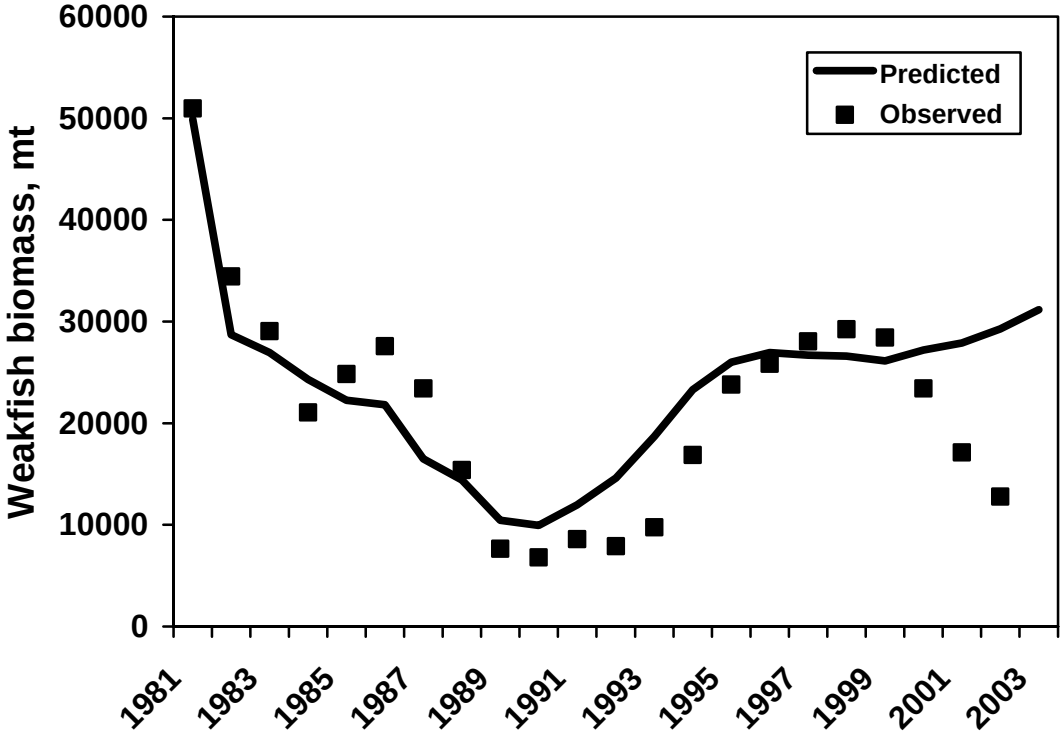


**Figure 35**. Weakfish biomass predicted from a logistic bluefish - weakfish predator-prey model and "observed" weakfish biomass from rescaled relative F analysis. Both are based on the same MRFSS catch per effort index for weakfish.

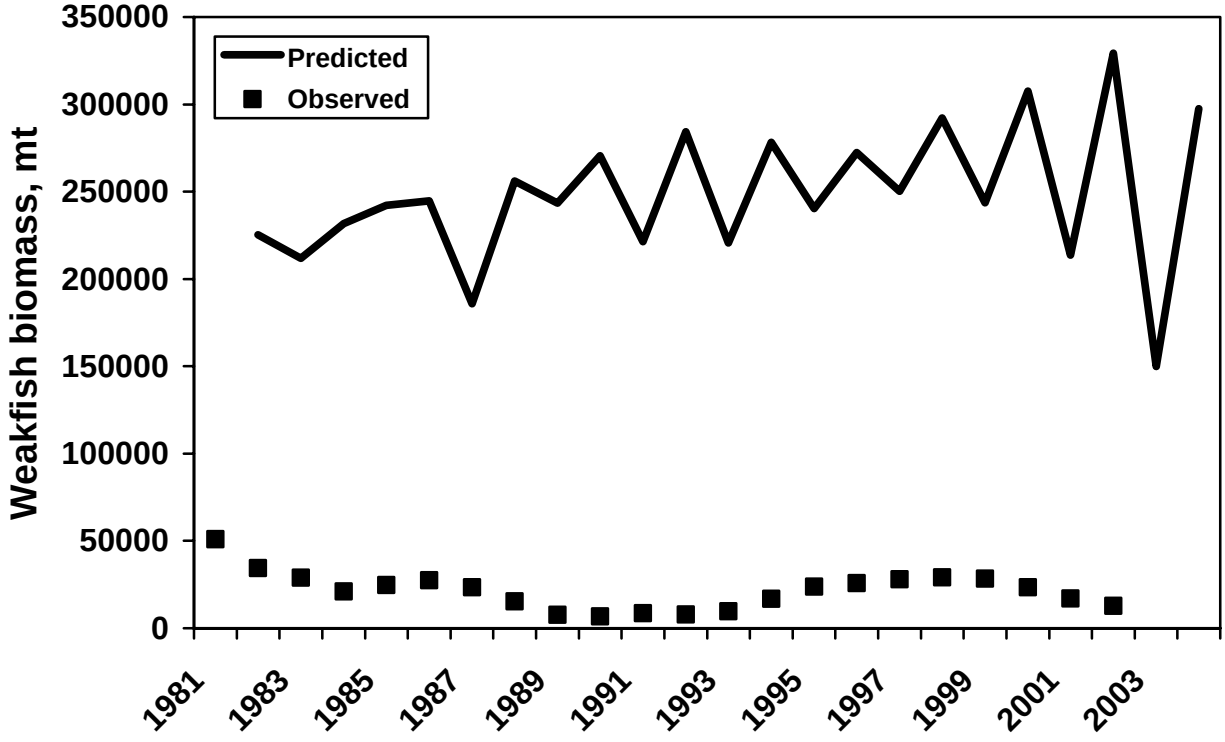


**Figure 36**. Weakfish biomass predicted from a logistic summer flounder - weakfish predator-prey model and "observed" weakfish biomass from rescaled relative F analysis. Both are based on the same MRFSS catch per effort index for weakfish.

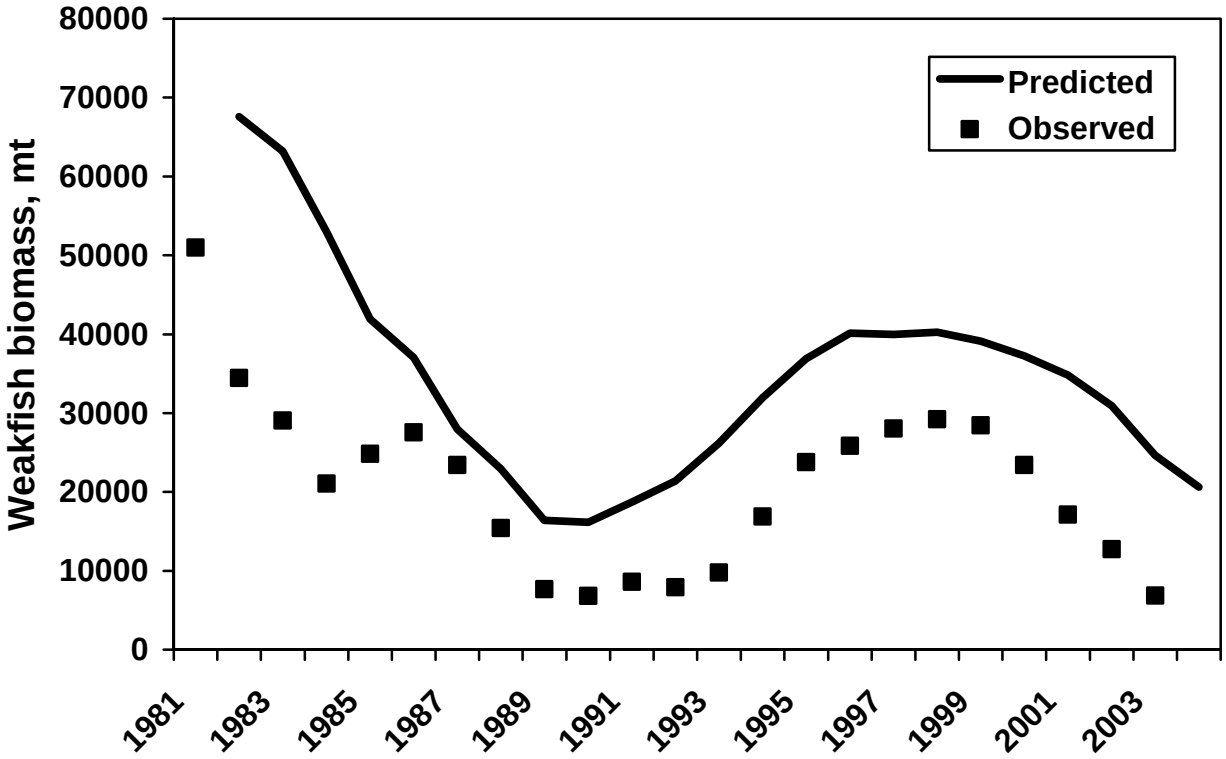


**Figure 37**. Weakfish biomass predicted from a logistic spiny dogfish - weakfish predator-prey model and "observed" weakfish biomass from rescaled relative F analysis. Both are based on the same MRFSS catch per effort index for weakfish.

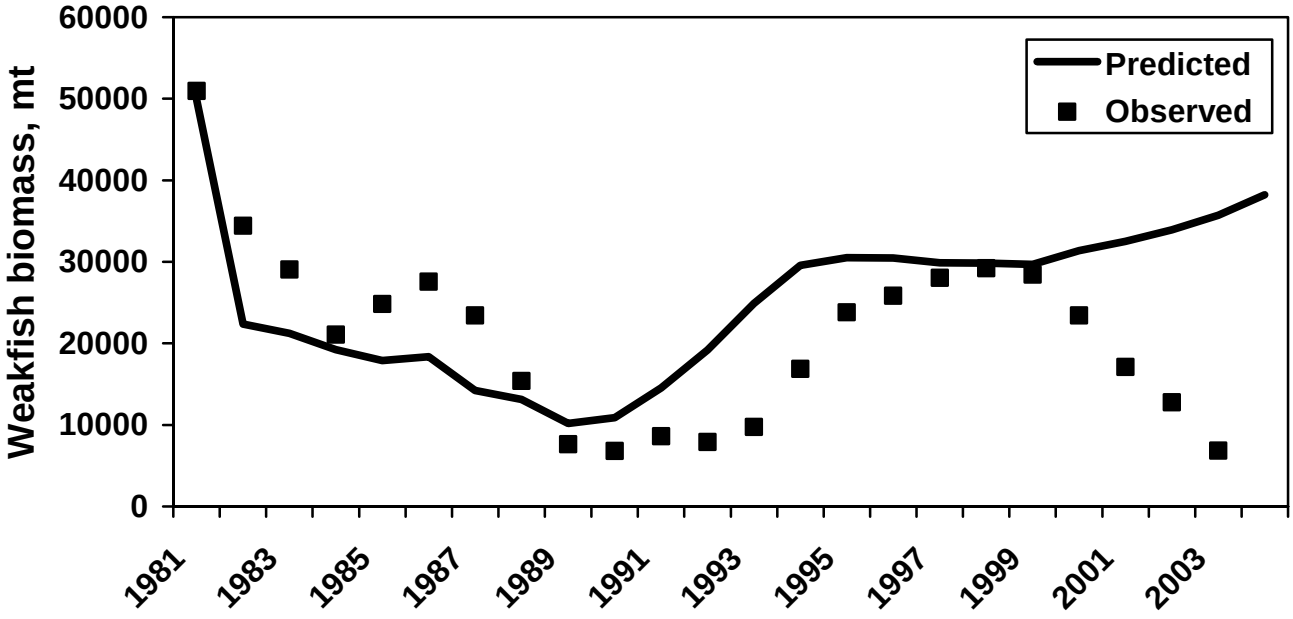


**Figure 38**. Weakfish biomass predicted from striped bass and summer flounder - weakfish logistic predator -prey model and "observed" weakfish biomass from rescaled relative F analysis. Both are based on the same MRFSS catch per effort index for weakfish.

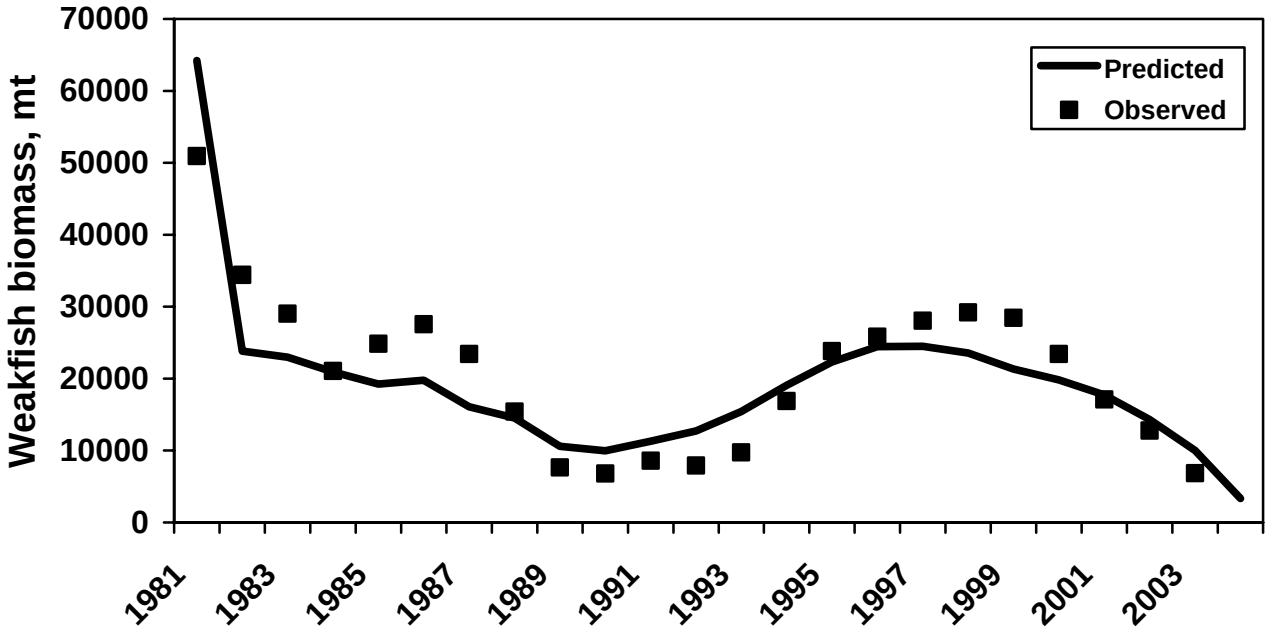


**Figure 39**. Standardized age 0 weakfish indices from Crecco (2006). Nj (grand mean) indicates general trend.

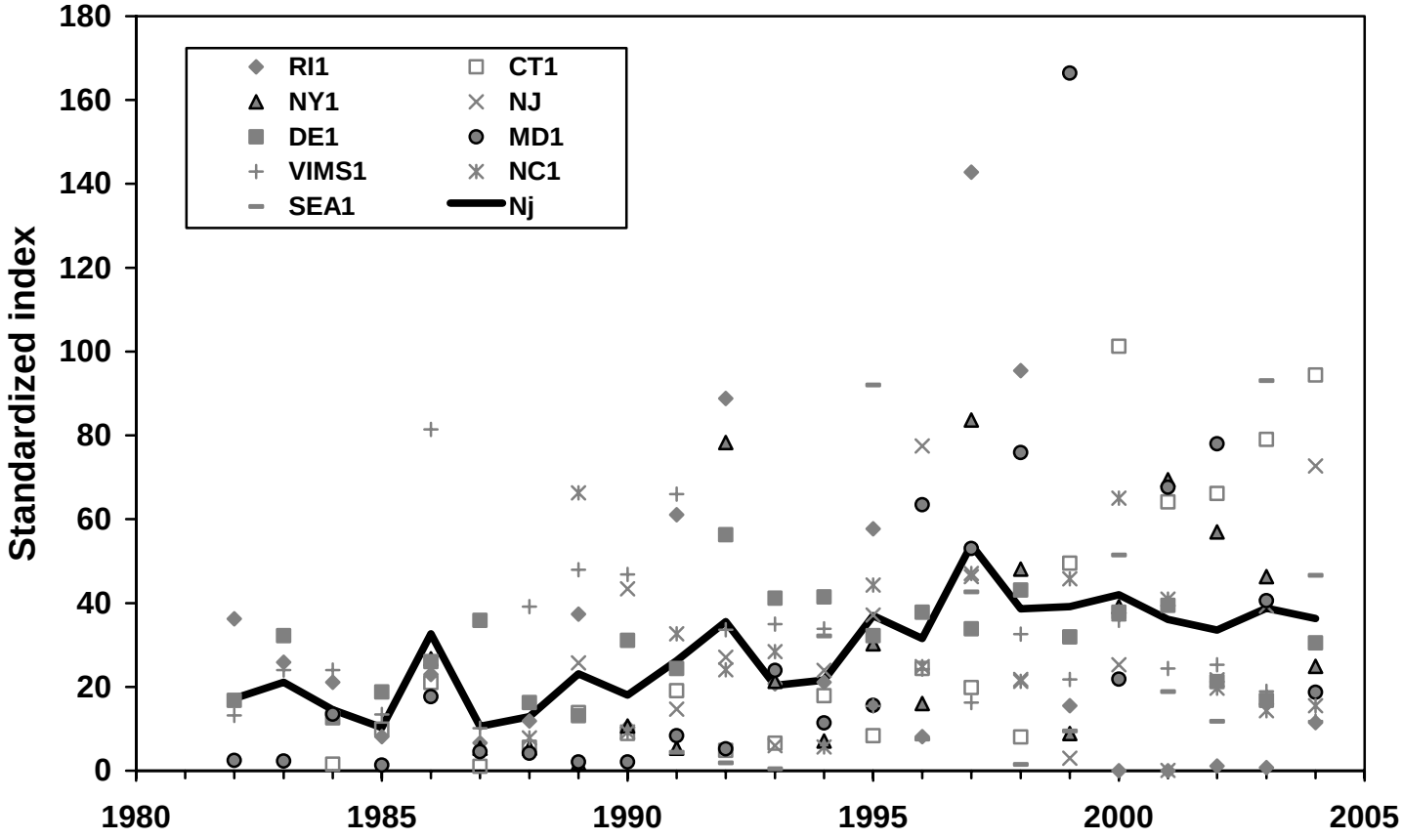


**Figure 40**. Decreased menhaden : bass ratio corresponded to increased weakfish M attributed to bass competition and predation. Note: rapid rise in M estimates as the ratio becomes asymptotically low in the mid-1990s. Age 0 weakfish mortality index (RZj; Crecco 2006) has been divided by 4 to scale it to the plot.

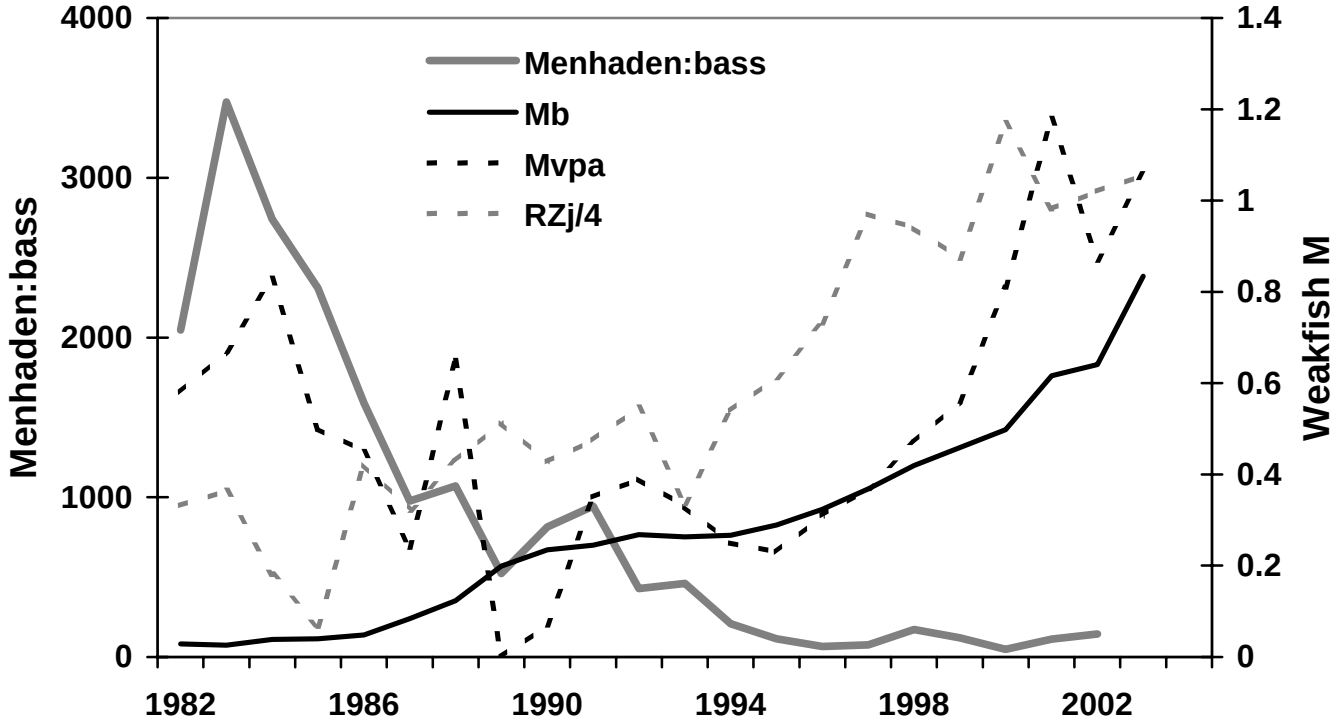
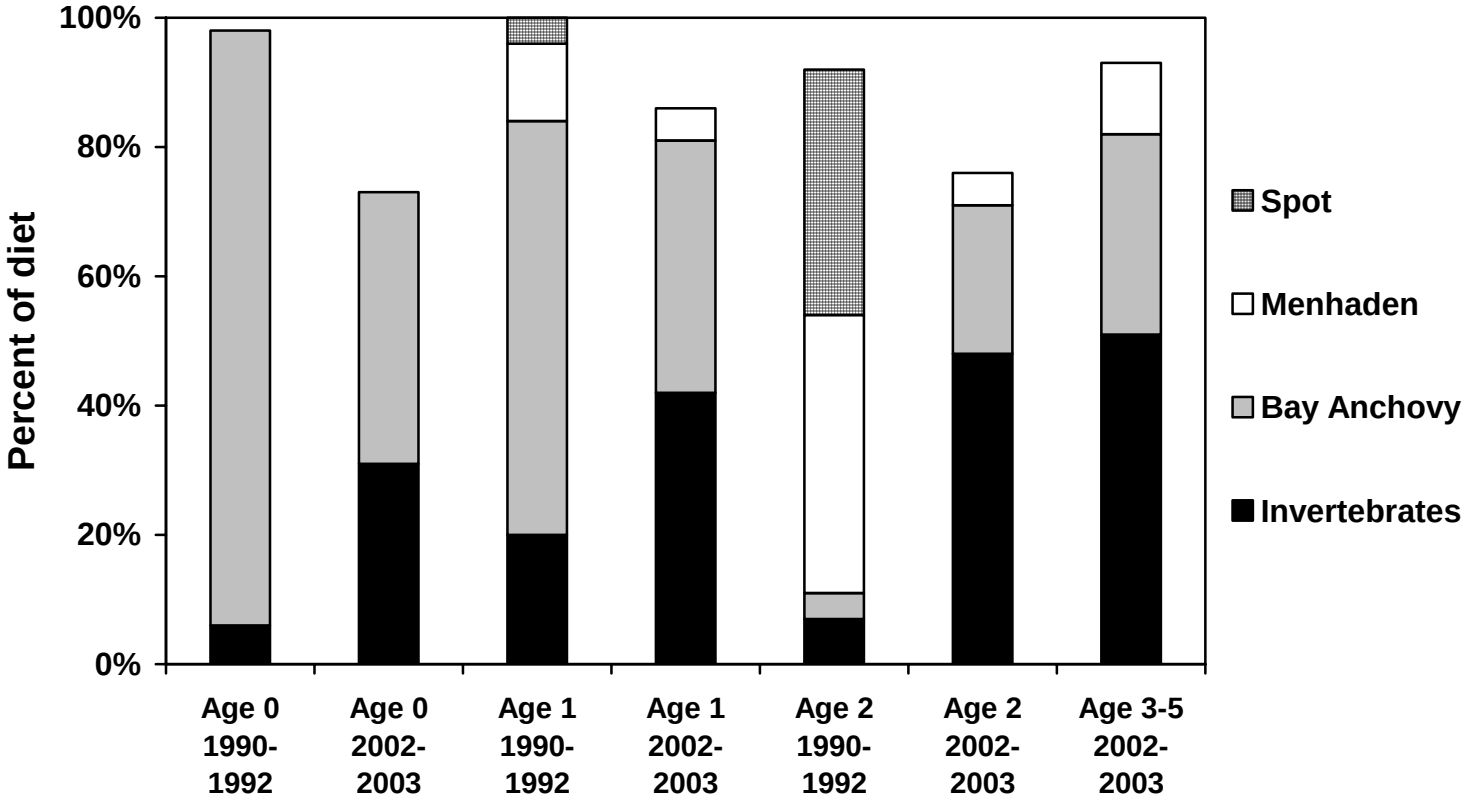
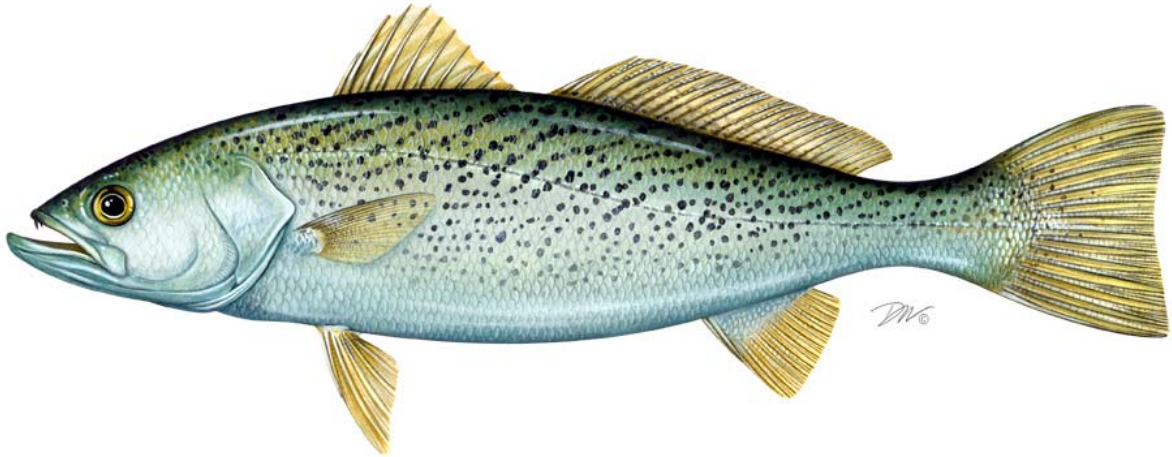


**Figure 41**. Comparison of age-specific weakfish diets (by weight) in Chesapeake during 1990-1992 and 2002-2003. Data for 1990-1992 were from Hartman and Brandt (1995) and data for 2002-2003 were provided by R. Latour (VIMS).



# Atlantic States Marine Fisheries Commission

## *Terms of Reference & Advisory Report to the Weakfish Stock Assessment Peer Review*



## April 2006

***Healthy, self-sustaining populations for all Atlantic coast fish species or successful restoration well in progress by the year 2015***

# Atlantic States Marine Fisheries Commission

## *Terms of Reference & Advisory Report to Weakfish Stock Assessment Peer Review*

Conducted on
March 20-22, 2006
Providence, RI

Dr. Brian J. Rothschild, Panel Chair, University of Massachusetts – Dartmouth
Dr. Steven X. Cadrin, NOAA/UMass Cooperative Marine Education and Research Program
Dr. Steven J. D. Martell, University of British Columbia
Dr. Ransom A. Myers, Dalhousie University

A publication of the Atlantic States Marine Fisheries Commission pursuant to National Oceanic and Atmospheric Administration Award No NA05NMF4741025.

## Preface

*Summary of the Commission Peer Review Process*

The Benchmark Stock Assessment Peer Review Process, adopted in October 1998 and revised in 2002 and 2005 by the Atlantic States Marine Fisheries Commission (ASMFC or Commission), was developed to standardize the process of stock assessment reviews and validate the Commission's stock assessments. The purpose of the peer review process is to: (1) ensure that stock assessments for all species managed by the Commission periodically undergo a formal peer review; (2) improve the quality of Commission stock assessments; (3) improve the credibility of the scientific basis for management; and (4) improve public understanding of fisheries stock assessments. The Commission stock assessment review process includes evaluation of input data, model development, model assumptions, scientific advice, and review of broad scientific issues, where appropriate.

The Commission's Benchmark Stock Assessment Peer Review Process outlines options for conducting an external peer review of Commission managed species. These options are:

1. The Stock Assessment Workshop/Stock Assessment Review Committee (SAW/SARC) conducted by the National Marine Fisheries Service (NMFS), Northeast Fisheries Science Center (NEFSC).

2. The Southeast Data and Assessment Review (SEDAR) conducted by the National Marine Fisheries Service, Southeast Fisheries Science Center (SEFSC).

3. The Transboundary Resources Assessment Committee (TRAC) reviews stock assessments for the shared resources across the USA-Canada boundary and it is conducted jointly through the National Marine Fisheries Service and the Canada Department of Fisheries and Oceans (DFO).

4. An external Commission stock assessment review panel conducted by 3-4 stock assessment biologists (state, federal, university). The Commission review panel will include scientists from outside the range of the species to improve objectivity.

5. A formal review using the structure of existing organizations (i.e. American Fisheries Society, International Council for Exploration of the Sea, or the National Academy of Sciences).

The ASMFC Weakfish Stock Assessment Peer Review Panel (Option 4 from above) met on March 20-22, 2006 in Providence, Rhode Island to review the Weakfish Stock Assessment.

*Purpose of the Terms of Reference and Advisory Report*

The Terms of Reference and Advisory Report provides summary information concerning the weakfish stock assessment and results of the External Peer Review to evaluate the accuracy of the data and assessment methods for this species. Specific details of the assessment are documented in a supplemental report entitled Weakfish Stock Assessment Report for Peer Review. A copy of the supplemental report can be obtained via the Commission's website at www.asmfc.org under the Weakfish page or by contacting the Commission at (202) 289-6400.

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## TERMS OF REFERENCE FOR THE WEAKFISH PEER REVIEW

The ASMFC Weakfish Stock Assessment Peer Review Panel (Panel) does not endorse the recommendations of the ASMFC Weakfish Technical Committee (TC) regarding stock status of weakfish along the Atlantic coast. The TC based its conclusions on a biomass dynamics model that included striped bass predation. The Panel feels that the biomass dynamic model relies too heavily on recreational catch per unit effort (CPUE) data that excludes a portion of the geographic range of weakfish and that the model excludes information on relative stock size from research surveys. The Panel felt that there was insufficient attention to the fact that juvenile survey abundance indices were generally increasing over the time series and too much reliance on the assumption that recent trends in landings directly reflect abundance. The TC did not fully consider the substantial portion of catch being discarded (e.g., commercial and recreational discards increased since 1994 and in 2003 reported discards were greater than total landings). Evidence for predation of exploitable size weakfish by striped bass is weak. Furthermore, if geographic stock structure were considered in analysis of these data, conclusions about stock status may be different than those provided by the TC.

**1. Characterize commercial and recreational catch including landings and discards.**

There is evidence of stock structure. Nesbitt (1954) indicated at least three stocks from tagging and Thorrold et al. (2001) indicated high fidelity of weakfish to their natal estuary, and there is substantial regional heterogeneity in population dynamics of stock structure. The fact that geographic stock structure has not been included in the analysis may explain the observed annual variation in growth and mortality. Taking account of stock structure would probably reduce uncertainty in the assessment and lead to better stock status determination on a regional basis.

Despite the evidence for stock structure, weakfish along the coast have been assumed to be single stock. All assessments to date have been based on this assumption. In fact, data have been pooled as if there had been a single stock and consequently the appropriate statistical weights among stocks have not been determined.

Commercial landings since 1950 appear to be estimated with moderate precision and landings since 1994 appear to be well estimated; however, given that weakfish are often taken as bycatch and have relatively low value, the overall estimates may be less accurate than the TC believes. The TC felt that the National Marine Fisheries Service (NMFS) Marine Recreational Fisheries Statistics Survey (MRFSS) recreational landings since 1981 are well estimated, but the Panel was concerned that there was substantial uncertainty in the MRFSS estimates. The accuracy of these data may be heterogeneous over regions and time. The panel noted some inconsistencies in the various catch tables, where the total estimated landings from all fisheries are not equal in the various tables that presented total landings.

The discard patterns are not what we would expect given the change in regulations in the mid-1990s. Discards rates varied in recent years (proportion of total commercial catch that was discarded: 1999 – 51%, 2000 – 17%, 2001 – 55%, 2002 – 61%). The high discards rates are a concern for conservation and management of weakfish, as most estimates of discard rates are generally underreported given the change in fishermen behavior when observers are onboard vessels. Commercial discards are estimated with moderate precision to1994, but there are no direct data in earlier years. Recreational discards are estimated with moderate precision since 1981. Discard mortality is uncertain (assumed variable by commercial gears and assumed 20% for the recreational fishery).

Dedicated age-length keys are unavailable for most potions of the catch (e.g., northern portions of commercial fishery, all recreational catch, some surveys, commercial discards before 1994). Overlap among ages for small fish is worrisome because this probably adds considerable bias in the catch-age information that used in the ADAPT virtual population analysis (VPA; NOAA Fisheries Toolbox Version, 2004. VPA/ADAPT, Version 2.1.9. [Internet address: http://nft.nefsc.noaa.gov ]). Geographic patterns in growth may confound estimation of catch-at-age. Age-structure is poorly estimated particularly for recreational and commercial discarded portions of the catch.

There are major problems with the calculations of the catch-at-age as indicated by substantial sum of products differences (Catch at age * mean weight at age does not equal the estimates of catch biomass). Abrupt changes in mean weight-at-age data may result from errors in the calculation of the catch-at-age. The changes in mean weight are coincident with a conversion from scale ages to otolith ages. The Panel was not afforded the opportunity to review a statistical analysis of the scale-otolith conversions. In addition, there was no information from fishery independent surveys on changes in growth in the stock assessment report.

There are substantial deficiencies in biological samples (i.e. age and length) in some regions (Table 2A in the stock assessment report). Particularly notable is the absence of sampling in New York or New Jersey; thus, it is impossible to make precise evaluation of this stock without information from this region. It seems likely that larger and older fish migrate further north seasonally and may be less represented in the sampling, given the lack of data from these regions. Estimates of total mortality from sample catch-at-age assume that older fish are fully represented in the samples. Some age-length samples are collected with the intention of obtaining estimates of growth; therefore, they are not representative of age-frequency of the catch (e.g., North Carolina).

In conclusion, deficiencies in stock identification and sampling make this stock assessment very difficult to validate. The age-composition of the catch may not be reliable (e.g., no validation of annuli in otolith based ages, in scale based ages, or in the relationship of otolith to scale based ages); therefore, the results from the ADAPT and subsequent analyses dependent upon these results are suspect, as VPA assumes no errors in catch-at-age.

**2. Review adequacy and uncertainty of fishery-independent and dependent indices of relative abundance.**

*Fishery Independent Surveys*

There is a lot of information in the fishery independent surveys, but the information is noisy and difficult to interpret. However, there are consistent long-term trends in the young of year indices among almost all of the surveys. Including all of the survey information into a VPA calibration, in the form assumed by ADAPT, implicitly assumes equal weighting of all surveys regardless of geographic coverage, representativeness, or statistical properties. The TC believed that ADAPT would be able to sort out the different survey variances; however, ADAPT is not capable of doing so. Spatial analysis of fishery and survey data would help to determine what the portions of the resource the data represent. In general, a comprehensive review of the use of state and federal survey fishery independent surveys would benefit ASMFC stock assessments.

The TC evaluated the following four fishery independent surveys: the NMFS fall inshore trawl survey, the New Jersey ocean trawl survey, the Delaware trawl survey, and the SEAMAP trawl survey). Other surveys were included in a graphical analysis of the young of year trends.

Both the TC and the Panel felt the NMFS Northeast Fisheries Science Center's fall inshore survey had the broadest geographic coverage of available surveys, could be used to monitor long-term trends of relative

abundance, and tracked some cohorts well. Concerns with the survey as an indicator of abundance include the interannual variability of the timing of the survey relative to weakfish migration, the fact that the survey only catches young weakfish, catch curve analysis from the survey yields negative estimates of total mortality rates (Z), and confounding temperature effects. The survey has a dedicated age-length key and fish were initially aged by scales before changing to otoliths.

Trends of relative weakfish abundance for the New Jersey ocean trawl survey were consistent with perception of weakfish stock development up to mid-1990s, but were then inconsistent with fishery catch rates. The survey is limited to sampling the coastal ocean of New Jersey. The survey is conducted five times per year in January, April, June, August, and October, but only survey tows from August and October were used to develop the weakfish index and there was a skewed distribution of catches. Age data are available for some years, but in others age data were 'borrowed' from adjacent surveys.

Although the Delaware Bay trawl survey sampling area is limited geographically, it is located near the center of weakfish population abundance. The survey is conducted monthly with dedicated age samples, and abundance-at-age patterns are generally consistent (e.g., all Z estimates are positive).

The SEAMAP survey is the southern most survey examined by the Weakfish TC. The survey is conducted in spring, summer, and fall from Cape Hatteras, North Carolina to Cape Canaveral, Florida, but only data from the fall survey from North Carolina were utilized. The abundance-at-age patterns are generally consistent, as evident by positive Z estimates from cohort catch curve analysis, but the index is noisy. Some age data are available from the SEAMAP survey; however, for years when no ages were available, age data were 'borrowed' from adjacent surveys.

*Fishery dependent indices*

Commercial catch per unit effort indices (from North Carolina) were presented to the Panel. Catch per unit effort for both the North Carolina estuarine commercial gears and the North Carolina ocean winter fishery were affected by regulations in 1994 and only cover a small portion of the geographic range of weakfish.

The TC utilized a recreational CPUE based on the NMFS MRFSS using mid-Atlantic private boat CPUE (all trips or trips targeting black sea bass, bluefish, Atlantic croaker, summer flounder, weakfish, and spot). This index includes kept and released catch and, compared to the commercial indices, is less affected by regulations. This fleet historically accounted for a small component of total catch (11% in 1989, 12% in 1990), but accounts for more than 50% in recent years and does not account for trends in abundance outside the fished area (North, South, and offshore). For the recreational fishery, there are no dedicated age data and no lengths are available for the released portion; therefore, 'borrowed' age-length keys were applied from commercial and survey data, which could have caused a false consistency with the catch-at-age.

Each fishery dependent index has nuances with catchability (i.e., technological changes), which were not discussed. The mid-Atlantic private boat fleet appears not to reflect abundance. For example, there is a concern that a proportion of the stock migrates out of the mid-Atlantic area and that proportion varies annually, which would affect the catchability of the mid-Atlantic private boat fleet.

The Panel concluded that fishery independent survey data requires a more comprehensive analysis to get a coast wide perception of relative stock size and that fishery dependent indices may not be a reliable indicator of stock size.

**3. Review the appropriateness of constant and variable natural mortality (M) estimates in the assessment.**

The sampled age-structure indicates extraordinarily high Z estimates during periods of low catch, suggesting that M rates are high. However, there are two additional reasons that Z could be inflated, 1) older ages are truncated by the selectivity of the gear and 2) catches of older fish in areas where fish are not sampled (e.g., New Jersey).

The TC makes the case for increasing Z based on the ADAPT (Run #20 – the preferred run from Stock Assessment Report). All other ADAPT analyses indicate that total mortality is decreasing. The distinguishing feature of Run #20 is that it is tuned solely with the recreational CPUE from the mid-Atlantic private boats. All of the subsequent analyses were dependent upon the results of Run #20. The Panel found the results from the ADAPT and subsequent analyses dependent upon these results are suspect.

Inferences on changes in M were based on nominal fishing effort (in units of private boat day in the mid-Atlantic, $f$ = catch divided by CPUE) scaled to ADAPT estimates of fishing mortality rate from Run #20 over 1987 to 1991 where M was assumed to be 0.25. This short time period may reflect atypical catchability based on migration of weakfish (mid-Atlantic private boat catch was as low as 10% of total catch during this time period, but was much higher in other periods). Changes in M were calculated to be the residual between estimates of fishing mortality rates (F) and Z where the F came from the VPA estimates.

The TC tried to explain the increase in Z as increased predation mortality by striped bass using a production model coupled with a Type III functional response. No statistics were presented that allowed the Panel to evaluate the Steele-Henderson model relative to models that assume constant M. The evidence for striped bass predation on exploitable sized weakfish is weak. The Steele-Henderson model is inappropriate for the interactions among striped bass, weakfish, and menhaden, because it assumes that predation occurs only on fish that are fully vulnerable to the fishing gear and ignores predation on smaller fish.

A more rigorous approach to considering multispecies interactions would be to consider a precise hypothesis and incorporate the appropriate process in the population model. For example, if the precise hypothesis is predation of age-0 and age-1 weakfish by striped bass, then a stock recruitment function with a predation term would be appropriate. Alternatively, if competition with other piscivores were the precise hypothesis, then a competition term in the biomass dynamics model would be appropriate. The Steele-Henderson model applied by the TC would be appropriate for predation of exploitable size weakfish by striped bass. The Panel felt that the evidence for predation of exploitable size weakfish by striped bass is weak. Even if the hypothesis is well founded and the population process equation is appropriate, then accurate data on relative stock size and independent information on total mortality are needed.

If M has increased over time, then the corresponding estimate of $F_{msy}$ would be greater than the estimate of $F_{msy}$ that assumes constant M. If M is truly increasing, but we assume that it is constant, then we would advise for future F estimates that are less than the true $F_{msy}$. Conversely, if M is truly constant and we assume that it is increasing, we would recommend that future F estimates that are greater than $F_{msy}$. Therefore, assuming constant M is more risk averse than assuming an increase in M. This is why investigating variability in M is very important.

**4. Review the estimates of fishing mortality (F), spawning stock biomass, and total stock biomass for 1981-2004, and characterize the uncertainty of these estimates.**

The Panel applauds the effort to examine alternative explanations to the data (e.g., change in M) and appreciates creative solutions to these problems; however, the data are not adequate to test the hypothesis of increasing natural mortality of weakfish. Because this issue is so important along the Atlantic coast, it is worthwhile investigating historical data (i.e., data prior to 1981). The Panel encourages continued exploration of trophic dynamic models, as being conducted for other fishery resources with reduced productivity (e.g., the reduced productivity of cod throughout the north Atlantic). Members of the Panel recommended conducting tagging studies to directly measure changes in natural mortality rates.

The Panel was reluctant to recommend the use of any age-based analysis, given the questions about the reliability of the catch-at-age data. Refer to the discussion under Term of Reference 1 and 2 regarding poorly sampled catch-at-age and noisy survey indices.

There is some optimism for weakfish stock status, as recruitment has not declined in any portion of the range. Despite our uncertainty in stock productivity there is no apparent decrease in recruitment. In fact, evidence suggests that there have been recent increases in recruitment over the last 15 years. These differences in recruitment are correlated with substantial decreases in weight-at-age, which suggests that there is some limitation of weakfish carrying capacity. However, since no estimates of weight-at-age were provided for the survey data, this hypothesis was difficult to evaluate.

Estimated landings decreased since the early 1990s, but estimated discards increased since 1994. All indices of stock size indicate a positive response to the regulations during the early and mid 1990s. Since 1994, abundance indices are equivocal; some show an increase (NEFSC Fall; Connecticut and SEAMAP young-of-year surveys), some show no trend (New Jersey), and others a decrease (mid-Atlantic recreational CPUE) (see Figures 1 and 2).

The Panel is uncertain of the direction of Z, F, and M estimates, and, as a result, it is difficult to choose among alternative explanations of observed changes. Despite the uncertainty of recent indices of stock size, it appears that current regulations should be continued or strengthened to decrease discarded catch until a stronger indication of population response (decline or recovery) is seen. The Panel recommends that the ASMFC engage in a comprehensive monitoring program, including the estuarine and ocean environment that would help address short falls in stock assessments of weakfish and other species.

**5. Review the estimated biological reference points, as appropriate.**

For the reasons stated in Term of Reference 3, reference points from multispecies biomass dynamics model are not well estimated. Neither stock and recruitment analyses nor growth studies were presented to the Panel. In lieu of an accepted analytical assessment, conventional reference points are irrelevant and fisheries management needs to rely on historical measures of relative abundance (e.g., a period of high stock abundance from research surveys). Management needs to be adaptive to see if there is a response in the stock.

**6. Review stock projections.**

- **Review the projection of impacts on the stock of recent estimated rise in fishing mortality.**
- **Review the projection of stock response to reductions in fishing mortality given the estimated increase in natural mortality.**

The only projections presented to the Panel were based on the hypothesis of increased natural mortality. For the reasons stated in Term of Reference 3, these projections are not a reliable basis for management. In lieu of an alternate analytical model, projections were not available.

**7. Make research recommendations for improving data collection and assessment.**

The Panel makes the following research recommendations to improve weakfish data collection and stock assessment efforts:

Catch

- Sample age-composition of commercial catch throughout the range of the fishery.
- Continued observer coverage to estimate discards.
- Partition catch and catch samples by stock.
- Make a substantial investment in monitoring and assessment.
- Develop statistically efficient measurement of catch.
- Develop estimates of discard rates in the commercial fishery.
- Collect information on fishing effort (e.g., number of fishing vessels, number of units, and bycatch by gear).

Aging

- As recommended in SARC 40, further research should be conducted on growth (i.e. validation of scale to otolith conversion).
- Improve regional growth estimates, including studies of density dependent growth.
- Conduct a detailed analysis of the development of the age-length key.

Stock size indices

- Evaluate selectivity of gears (to improve estimates of Z).
- Conduct tagging studies to directly measure changes in natural mortality rates.
- Conduct a detailed analysis of the young of year surveys and the interrelationship among YOY surveys, and the design of a future comprehensive YOY survey.
- Focus on the development of very high resolution catch per unit of effort time series from among the various regions.
- Evaluate the effect of interannual variation on distribution and catchability.
- Conduct a comprehensive review of the use of state and federal survey fishery independent surveys for use in all ASMFC stock assessments.
- Development of analytic methods is needed to determine the status of the resources, which absolutely requires the development of more reliable data sets. Discounting a survey does not imply that it is not necessarily informative about the sub-stock in that region.
- Conduct a comprehensive monitoring program, including the estuarine and ocean environment. Such a program would address short falls in stock assessments of this and other ASMFC managed species.
- Conduct a comprehensive examination of the assemblages of species in a historical construct.

Growth

- A detailed analysis of factors affecting somatic growth should be carried out using data from research surveys if at all possible.

## Advisory Report

### Status of Stocks

The catch has decreased since the early 1990s. All indices of stock size indicate a positive response to the regulations enacted in Amendment 3 to the Weakfish Fishery Management Plan. Since 1994, survey indices are equivocal; some show an increase (NEFSC Fall, YOY – Connecticut, New Jersey, SEAMAP), some no trend (New Jersey), and others a decrease (Mid-Atlantic recreational CPUE).

Trends in mortality are uncertain. Despite the uncertainty of recent indices of stock size, it appears that current regulations should be continued or strengthened to decrease discarded catch until a stronger indication of population response (either a decline or a recovery) is seen.

### Stock Identification and Distribution

Weakfish are part of the Family Sciaenidae or "drums." Weakfish are found along the Atlantic coast with its primary range from North Carolina through southern New England and have been reported as far south as Florida and as far north as the Gulf of Maine. Weakfish are primarily estuarine and inshore oceanic inhabitants that migrate seasonally. In the autumn, they migrate south to North Carolina or Virginia coastal waters, where they overwinter. In spring weakfish move northward and inshore into estuarine spawning grounds including Pamlico Sound in North Carolina, Chesapeake and Delaware Bays and smaller coastal estuaries up through Gardiners Bay on eastern Long Island, New York and as far north as Long Island Sound and Narragansett Bay in Rhode Island.

The ASMFC Fisheries Management Plan considers weakfish to be a unit stock, based on genetic analysis (Graves et al. 1992). Recent work however, using geochemical composition of otoliths, found weakfish homed to their natal estuaries (Thorrold et al. 2001). Earlier tagging work performed in the 1930s also indicated that weakfish returned to their natal estuary (Nesbit 1954).

### Management Unit

The weakfish management unit spans the East Coast of the United States from Massachusetts through Florida.

### Fishery Description and Landings

Landings from 1950-2003 peaked in 1981. During the period from 1982-2004, landings were highest at the beginning, totaling about 12,500 mt in 1982. Landings declined in 1989 through 1993. An increase in landings began in 1995. Landings then peaked at above 5,000 mt in 1998. Weakfish landings began to decline again in 1999, which continued through 2004 to record low level. Trends of strong declines in recent years are seen in landings of weakfish by both the commercial and recreational sectors.

In the winter, overwintering aggregations off North Carolina are harvested by gill nets and fly net trawlers. Virginia and New Jersey also comprise an important component of commercial landings. During their annual migration, weakfish are harvested by a variety of estuarine gears, including gill nets, pound nets and floating traps, seines and hand lines. In the fall migration along the coast, weakfish aggregations are targeted with trawls and gill nets. In 1999, for instance, gill nets caught the largest share of the commercial landings, 48%, while trawl landings were second at 27%, followed by pound nets at 20% and haul seine at 5%.

Patterns in recreational total catch and harvest changed after imposition of minimum sizes and creel limits in 1995. After this time, total catch (A + B1 + B2 of the MRFSS) became significantly larger than harvest. This suggests that the regulations had a significant impact on recreational harvest, causing a large increase in live releases (discards).

In 1993, Virginia implemented a commercial fishermen mandatory reporting system, whereby each harvester reports daily activity (harvest, effort) on a monthly basis. This program replaced a voluntary buyer-reporting system. In 1994, North Carolina mandated trip-level reporting by licensed dealers for all commercial landings that requires dealers to complete a trip ticket for each transaction with a fisherman. These reports must be submitted monthly to the North Carolina Division of Marine Fisheries (NCDMF). Previously, the state had a voluntary reporting system from 1978-1993 obtained through a NMFS/NCDMF cooperative statistics program. In addition, NMFS implemented a mandatory electronic reporting system in 2004 for all federally permitted seafood buyers.

There are no explicit commercial discard estimates after 2002 and no information on the operation of the fishery. Only total catch and landings were provided in the Stock Assessment Report. The Panel had to calculate discards from total catch and landings. This information is crucial to understand the dynamics of fisheries impacts on the stock. In addition, the Panel found it important to consider how the "scrap" fishery affects commercial discard rates or biases the results of a production based model that assumes fixed selectivity.

The high discards rates pose an additional concern for conservation and management or weakfish, as most estimates of discard rates are generally underreported given the change in fishermen behavior when observers are onboard vessels.

**Data and Assessment**

In lieu of an accepted analytical stock assessment, status determination and advice are based on a descriptive summary of catch and survey data.

**Biological Reference Points / Fishing mortality**

For the reasons stated in Term of Reference 3, reference points from multispecies biomass dynamics model are not well estimated. Neither stock and recruitment analyses nor growth studies were presented to the Panel. In lieu of an analytical assessment, conventional reference points are irrelevant and fisheries management needs to rely on historical measures of relative abundance (e.g., a period of high stock abundance from research surveys). Management needs to be adaptive to see if there is a response in the stock.

**Recruitment / Spawning Stock Biomass**

There is some optimism for weakfish stock status. Despite uncertainty in stock productivity, recruitment has not declined in any portion of the range. In fact, evidence suggests that there has been a recent increase in recruitment over the last 15 years.

**Sources of Information**

Graves, J. E., J. R. McDowell and M. L. Jones. 1992. A genetic analysis of weakfish *Cynoscion regalis* stock structure along the mid-Atlantic Coast. Fishery Bulletin 90:469-475.

Nesbit, R. A. 1954. Weakfish migration in relation to conservation. Special Scientific Report - Fisheries No. 115. Fish and Wildlife Service, U. S. Dept. of the Interior.

Thorrold, S. R., C. Latkoczy, P. K. Swart and C. M. Jones. 2001. Natal homing in a marine fish Metapopulation. Science 291: 297-299.

## Figures

Figure 1. Relative abundance indices for age-0 weakfish from various fisheries independent surveys. The overall mean shows an increasing trend, but some show declining trends in recent years (e.g., VIMS) and others show increasing trends.

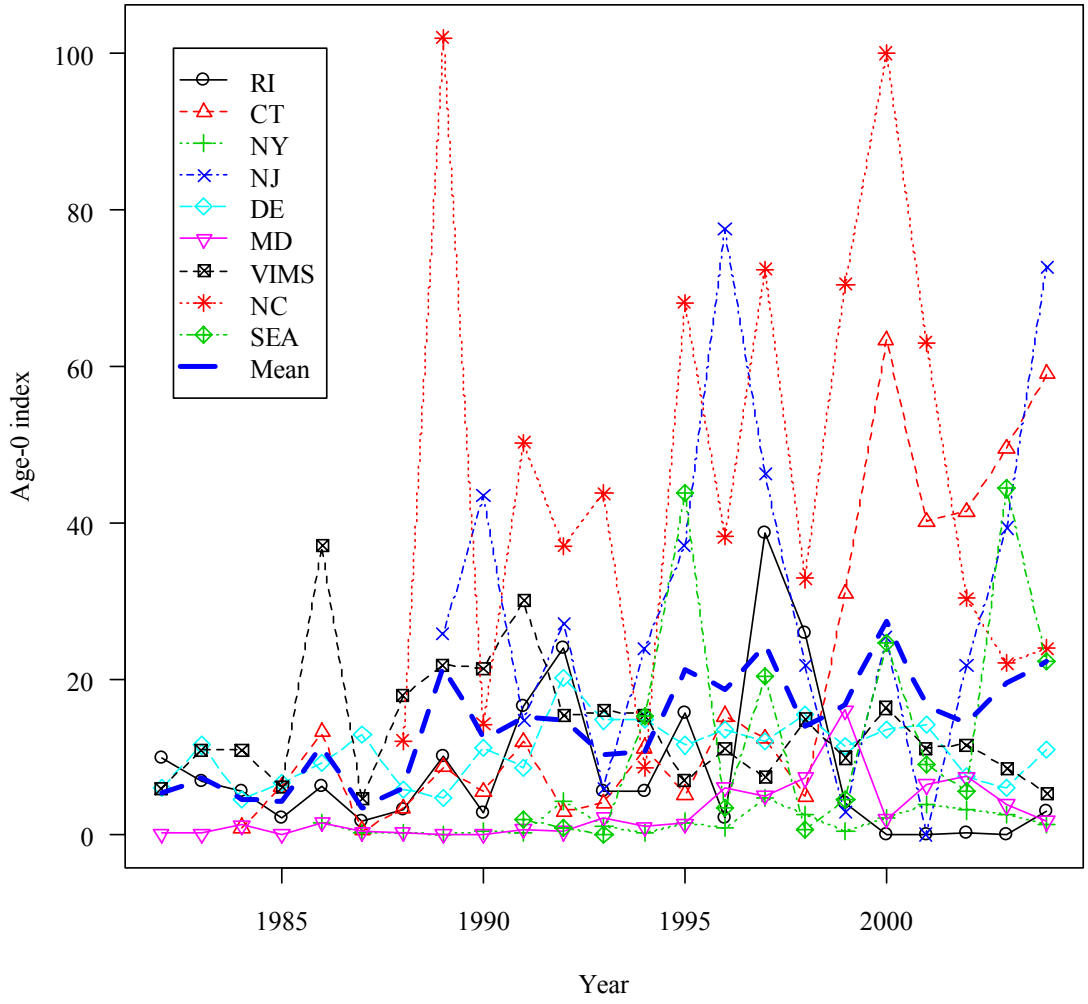
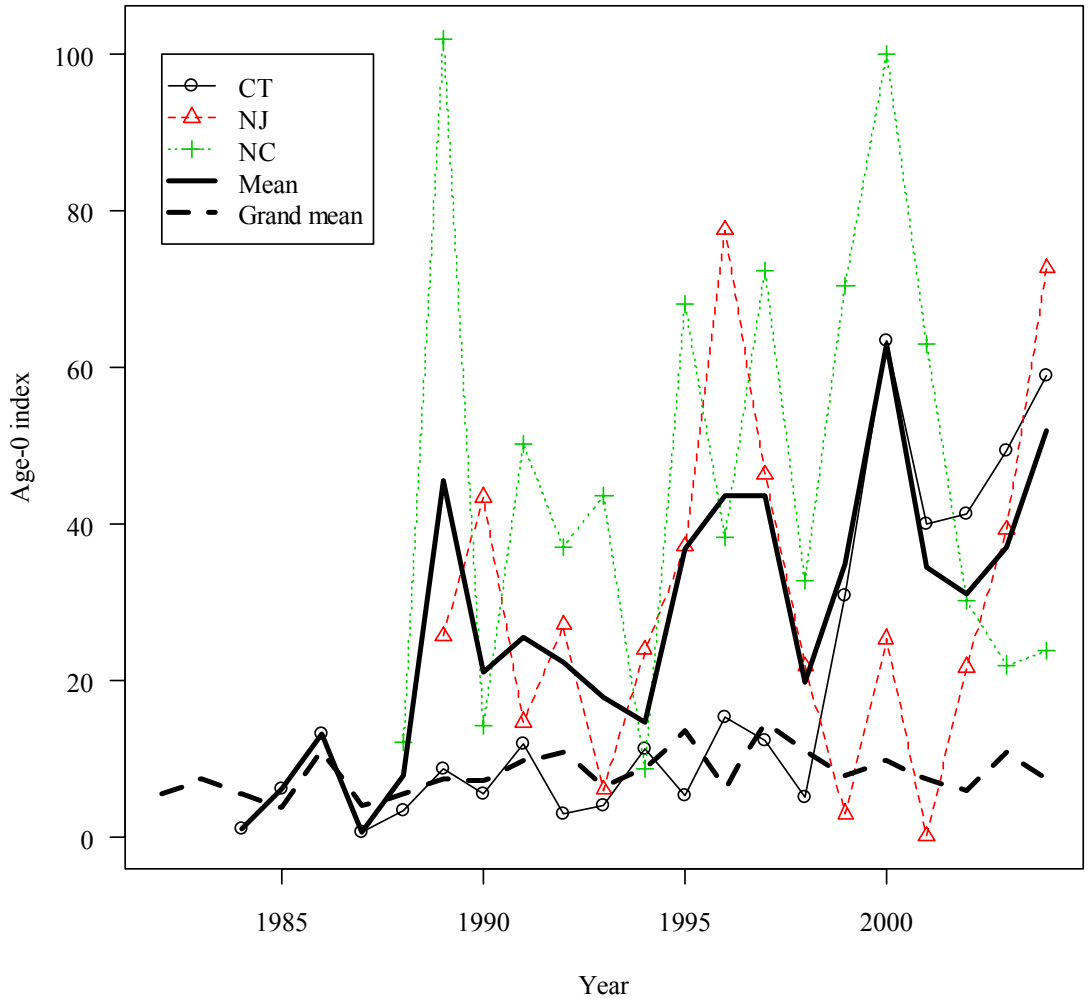


Figure 2. Age-0 abundance indices from the Connecticut (CT), New Jersey (NJ), and North Carolina (NC) fisheries independent surveys. The dark solid line is the mean trend of the CT, NJ, and NC surveys, and the dashed line is the trend of all other surveys shown in Figure 1. These trends suggest an increase in age-0 recruits to the fishery, but are inconsistent with the trends in the recreational CPUE index that was used for tuning the ADAPT VPA.



# Supplemental Material Requested by the Weakfish Management Board from the Weakfish Technical Committee following Peer Review

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## Implementation of 40th SARC Recommendations

Weakfish Technical Committee
June 2006

**Implemented Items: January 2005 – February 2006.**
*Commercial and recreational data should be examined with regard to its precision and accuracy, both in terms of absolute estimates of catches and its age composition.*
Aggregate catches:

1. Commercial catches are a census, so precision cannot be estimated. As with any species' landings, we assume they are accurate.
2. Recreational catch precision is estimated by MRFSS (PSE) and is acceptable. NRC (2006) review indicates serious shortcoming in estimates (any species) that may make accuracy doubtful.
3. Discard estimates and their precision were estimated by De Silva (2004). Precision is sometimes poor. Accuracy cannot be addressed.

Age composition of catches:
It is unclear how precision and accuracy of age structure could be addressed. Sampling of age composition from areas not well covered in the past (NY and NJ) could address a major TC concern about accuracy of CAA if an age-structured assessment is pursued.

*Evaluate information content of input data regarding year-class strength.*

1. Year-class catch curves of survey data were conducted and indicated only the DE large trawl survey provided suitable consistency (Kahn et al. 2006).
2. Bubble plot of CAA indicates year-classes can be followed over time (D. Kahn DEDFW, personal communication; presented to 2006 peer-review and Board).
3. Gulland-type cohort analysis of CAA provided estimates of N and F (Kahn et al. 2006).

*Validate ageing.*
Ageing of weakfish by otoliths has been validated in the primary literature (Lowerre-Barbieri et al. 1994). Further work for the TC was summarized by Wenner (1999).

*Develop age aggregated indices where CAA inconsistencies are problematic.*

1. Age aggregated biomass indices for trawl surveys were developed (Uphoff 2005; summarized in Kahn et al. 2006), evaluated, and accepted by TC.
2. Size structure indices were developed (Proportional Stock Density indices or PSD's (Uphoff 2004; summarized in Kahn et al. 2006), evaluated, and accepted by TC.
3. Age aggregated MRFSS-based recreational index was developed (Crecco 2005a; 2005b; Brust 2005), evaluated, and accepted by TC.

*Research into divergence of trawl survey indices and MRFSS index.*

1. Aggregated biomass indices evaluated (Uphoff 2006).
2. Correlation analysis indicates that MRFSS, DE, and NJ are significantly correlated. NEFSC significantly correlated with NJ and marginally with DE. MRFSS and NEFSC not correlated. MRFSS index was not "odd man out" (Uphoff 2006).
3. Inclusion of NEFSC with NJ and DE leads to most optimistic status.
4. Substitution of MRFSS for NEFSC indicates declining status.
5. PSD (length-frequency) analysis indicates proportion exploitable in NEFSC too small to estimate reliably (Uphoff 2004). NJ and DE sample sizes provide reliable, precise estimates, and are well correlated. MRFSS CPUE well correlated with PSD.
6. Assessment of index catchability (NEFSC, NJ, DE, MRFSS) and converged VPA biomass indicated MRFSS catchability was most consistent (Uphoff 2006). Survey catchability was much more variable and inverse relationships with biomass were suggested (Uphoff 2006).

*Review ecological and other explanations for possible decline of weakfish.*

1. Food web dysfunction was explored by Crecco (2005a; 2005c), Kahn et al. (2006), and Uphoff (2006).
2. Selected climatic variables (mean annual water temperatures (C) and annual deviations in the North Atlantic Oscillation index) were tested (Kahn et al. 2006).

**Items Not Implemented**

1. *Evaluate basic data for suitability of CAA approach.* The 30th SARC considered data adequate for CAA analysis, but they were not aware of the details on how the fisheries were sampled (i.e., NJ and NY missing samples). A detailed re-analysis of basic data was not started due to time constraints. The 2006 review casts doubt on applying an age-structured approach.
2. *Survey catch rates at age should be evaluated in space and time for consistent year-class signals.* Detailed spatial analysis has not been conducted on an age-structured or aggregated basis. TC may not have spatial analysis (GIS) expertise.
3. *Compare survey distributions to observed changes in pattern of landings to try and explain inconsistencies in trends in different series.*

## References


Brust, J. C. 2005. Development of a recreational CPUE index for weakfish using proxy data to estimate target effort. New Jersey Department of Natural Resources.

Crecco, V. 2005a. Fishing mortality (F), stock biomass, and overfishing thresholds for Atlantic Coast Weakfish from 1981-2003. Connecticut Marine Fisheries Division, Old Lyme. Connecticut Marine Fisheries Division, Old Lyme.

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Wenner, C. A. 1999. A summarization of the results of age determination of weakfish, *Cynoscion regalis*, by means of the examination of otoliths. A report to the Atlantic States Marine Fisheries Commission's Weakfish Technical Committee. Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston.

## Summary of Weakfish Technical Committee (TC) agreements and disagreements with the 2006 peer-review and the record of implementing recommendations of the 40th SARC

July 2006

Overall, the TC agreed with major statements in the review 9 times and disagreed 14; there were 2 agreements and 12 disagreements on main issues (top 4). Eight issues were identified by the 40th SARC and all but 2 were implemented by the TC. "TC Mean Rank" is the average rank of importance each TC member assigned to general issues in the peer-review (1 = most important & 9 = least). Columns labeled "Statements TC agrees" or "Statements TC disagrees" indicate the number of major statements in the peer-review relating to the general issue that the TC agreed or disagreed with; agreements or disagreements were unanimous among TC members. Number of disagreements does not constitute importance. Letters in "Agree statement & details" or "Disagree statement & details" columns refer to specific statements by the peer-review panel that can be found in Section 1 (pages 2-4 of this report). These letters also reference where details of TC agreements or disagreements can be located (Section 2, pages 5-18). "SARC 40 concern" indicates an issue present in 40th SARC panelist documents. NEFSC is the Northeast Fisheries Science Center index and MRFSS is the recreational catch index. CAA = catch at age.

| TC Mean Rank | 2006 Peer Review General Issue | Statements TC agrees | Statements TC disagrees | Agree statement & details | Disagree statement & details | SARC 40 concern | SARC 40 Implemented |
|---|---|---|---|---|---|---|---|
| 1.4 | Indices (NEFSC and JI's useful, MRFSS not) | 1 | 5 | P | K, L, M, N, V | Yes | Yes |
| 3.2 | Uncertain direction of Z, F, M, biomass | | 1 | | W | | |
| 4.1 | Food web / ecological explanations | 1 | 5 | O | Q, R, S, T, U | Yes | Yes |
| 4.4 | Landings not accurate (recreational, commercial, & discards) | | 1 | | D | Yes | Yes |
| 5.6 | CAA matrix problem - missing samples | 3 | 1 | C, E, H | F | Yes | No |
| 5.9 | Evidence of stock structure | 2 | | A, B | | | |
| 5.9 | Growth - survey estimates not provided | 1 | | J | | | |
| 5.9 | Growth - no validation | | 1 | | G | Yes | Yes |
| 6.4 | Spatial analysis could help | 1 | | I | | Yes | No |
| | **Sum for 2006 peer review** | **9** | **14** | | | | |
| | **SARC 40 Issue not in Peer-Review** | | | | | | |
| | CAA - evaluate indices | | | | | Yes | Yes |
| | Research divergence of trawl and MRFSS indices | | | | | Yes | Yes |

**Section 1: Specific Issues or Statements in the 2006 Peer Review Summarized in Table 1 Agree details or Disagree details columns. List is in order of appearance in the peer review document.**

*A. There is evidence of stock structure.*

*B. Taking account of stock structure would probably reduce uncertainty in the assessment and lead to better stock status determination on a regional basis.*

*C. Dedicated age-length keys are unavailable for most portions of the catch (e.g., northern portions of commercial fishery, all recreational catch, some surveys, commercial discards before 1994).*

*D. … given that weakfish are often taken as bycatch and have relatively low value, overall accuracy of landings may be less than TC believes.*

*E. Missing CAA samples (northern region), overlap of lengths-at-age, and geographic patterns in growth may confound estimation of CAA.*

*F. There are major problems with the calculations of the catch-at-age as indicated by substantial sum of products differences (Catch at age * mean weight at age does not equal the estimates of catch biomass).*

*G. No validation of annuli in otolith based ages, in scale based ages, or in relationship of otolith to scale based ages.*

*H. The age-composition of the catch may not be reliable (e.g., no validation of annuli in otolith based ages, in scale based ages, or in the relationship of otolith to scale based; therefore, the results from the ADAPT and subsequent analyses dependent upon these results are suspect, as VPA assumes no errors in catch-at-age.*

*I. Spatial analysis of fishery and survey data would help to determine what the portions of the resource the data represent.*

*J. No information from fishery independent surveys on changes in growth was presented.*

*K. The TC believed that ADAPT would be able to sort out the different survey variances; however, ADAPT is not capable of doing so.*

*L. Both the TC and Panel felt the NEFSC fall inshore survey had the broadest geographic coverage of available surveys, could be used to monitor long-term trends of relative abundance, and tracked some cohorts well.*

*M. Each fishery dependent index [in this case, the MRFSS aggregated biomass index] has nuances with catchability (i.e., technological changes) which were not discussed. The mid-Atlantic fleet appears not to reflect abundance. For example, there is a concern that a proportion of the stock migrates out of the mid-Atlantic area and that proportion varies annually, which would affect the catchability of the mid-Atlantic private boat fleet.*

*N. This [private boat] fleet historically accounted for a small component of total catch (11% in 1989, 12% in 1990), but accounts for more than 50% in recent years and does not account for trends in abundance outside the fished area (North, South, and offshore).*

*O. The sampled age-structure indicates extraordinarily high Z estimates during periods of low catch, suggesting that M rates are high. However, there are two additional reasons that Z could be inflated, 1) older ages are truncated by the selectivity of the gear and 2) catches of older fish in areas where fish are not sampled (e.g., New Jersey).*

*P. The TC makes the case for increasing Z based on the ADAPT Run #20 (the preferred run from Stock Assessment Report). All other ADAPT analyses indicate that total mortality is decreasing. The distinguishing feature of Run #20 is that it is tuned solely with the recreational CPUE from the mid-Atlantic private boats. All of the subsequent analyses were dependent upon the results of Run #20.*

*Q. The TC tried to explain the increase in Z as increased predation mortality by striped bass using a production model coupled with a Type III functional response. No statistics were presented that allowed the Panel to evaluate the Steele-Henderson model relative to models that assume constant M.*

*R. The evidence for striped bass predation on exploitable sized weakfish is weak. The Steele-Henderson model is inappropriate for the interactions among striped bass, weakfish, and menhaden, because it assumes that predation occurs only on fish that are fully vulnerable to the fishing gear and ignores predation on smaller fish.*

*S. A more rigorous approach to considering multispecies interactions would be to consider a precise hypothesis and incorporate the appropriate process in the population model.*

*T. For example, if the precise hypothesis is predation of age-0 and age-1 weakfish by striped bass, then a stock recruitment function with a predation term would be appropriate.*

*U. If M has increased over time, then the corresponding estimate of $F_{msy}$ would be greater than the estimate of $F_{msy}$ that assumes constant M. If M is truly increasing, but we assume that it is constant, then we would advise for future F estimates that are less than the true $F_{msy}$. Conversely, if M is truly constant and we assume that it is increasing, we would recommend that future F estimates that are greater than $F_{msy}$. Therefore, assuming constant M is more risk averse than assuming an increase in M.*

*V. There is some optimism for weakfish stock status, as recruitment has not declined in any portion of the range. Despite our uncertainty in stock productivity there is no apparent decrease in recruitment. In fact, evidence suggests that there have been recent increases in recruitment over the last 15 years.*

*W. The Panel is uncertain of the direction of Z, F, and M estimates, and, as a result, it is difficult to choose among alternative explanations of observed changes.*

## Section 2: Details of Agreements and Disagreements with the April 2006 Peer Review Panel Outlined in Table 1

**Format of Section 2**

This section provides detailed responses to the Peer review panel comments (in italics) that are represented by letters in Table 1 and listed in order of appearance (and lettered) in Section 1. The TC agreement or disagreement is in bold. An additional response from the TC is in normal type. Part 1 or Part 2 in the text refers to sections of the weakfish assessment. References can be found in the report on the TC response to the 40th SARC.

**What was the TC trying to do?**

1. **Answer the question "Is the stock declining?"**
2. **If so, what are the likely underlying causes for the decline?**

Some important aspects of the assessment were not addressed by the Panel. Development of aggregated biomass indices, estimates of relative F (catch / index), proportional stock densities (PSD, a length structure index), biomass dynamic modeling without predation, and the concept of rescaling relative F to absolute F units were not commented on.

**Peer Review Section 1. Characterize commercial and recreational catch including landings and discards.**

*A. There is evidence of stock structure.*

**TC Agrees**

It has been discussed regularly in the past decade. The TC provided stock structure information to the panel and has summarized it for the Board for this meeting (August 2006). Tagging, meristics, and otolith microchemistry support regional dynamics, but suggest moderate exchange among regions. Genetic analyses indicate largely homogeneous populations. The TC notes that difficulty in defining stocks and implementing stock-specific assessments in a mixed stock fishery would be major obstacles.

<u>Other ASMFC assessments (striped bass, Atlantic menhaden, and red drum) have known or potential stock structure, but are assessed as single stocks.</u>

*B. Taking account of stock structure would probably reduce uncertainty in the assessment and lead to better stock status determination on a regional basis.*

**TC Agrees**

- TC agrees that evidence of stock structure exists.
- But there is inadequate data and enough potential mixing that pinpointing where to split is questionable.

*C. Dedicated age-length keys are unavailable for most portions of the catch (e.g., northern portions of commercial fishery, all recreational catch, some surveys, commercial discards before 1994).*

**TC Agrees**

The TC notes that this is not a feature restricted to the weakfish assessment alone. In particular, all ASMFC age-structured assessments (striped bass, summer flounder, bluefish) that feature recreational catches rely on borrowed age-length distributions.

*D. … given that weakfish are often taken as bycatch and have relatively low value, overall accuracy of landings may be less than TC believes.*

**TC Disagrees**

The TC did not express an opinion on the accuracy of landings. The assessment used landings as they are used in other assessments.

4. Weakfish are valuable and most major harvesting states have or had directed fisheries.
5. Directed landings and legal bycatch are recorded.
6. Prior to imposition of Amendments 2-4, regulation was minimal and there was little regulatory reason for discarding.
7. Weakfish recreational catches (survey methodology) follow commercial catches (census methodology) closely (correlation r = 0.86).
8. Discard estimates and their precision were estimated by De Silva (2004). Precision is sometimes poor. Accuracy cannot be addressed.
9. Including and excluding discards had little effect on assessment trends and estimates.
10. Amount of commercial discards needed to account for decline is much larger than current estimates (3-13 X's in 2003) based on modeling. Evidence does not point toward any Atlantic coast fishery capable of generating 3,000-13,000 mt of additional unreported weakfish discards. The results of these bycatch scenarios taken at face value suggest that weakfish regulations created this massive boost in discards.

*E. Missing CAA samples (northern region), overlap of lengths-at-age, and geographic patterns in growth may confound estimation of CAA.*

**TC Agrees**

*F. There are major problems with the calculations of the catch-at-age as indicated by substantial sum of products differences (Catch at age * mean weight at age does not equal the estimates of catch biomass).*

**TC Disagrees**

Part 1, Figure 15 indicates good agreement during 1981-2003, except for two years in the late 1980s.

*G. No validation of annuli in otolith based ages, in scale based ages, or in relationship of otolith to scale based ages.*

**TC Disagrees**

Ageing of weakfish by otoliths has been validated in the primary literature (Lowerre-Barbieri et al. 1994). Further work for the TC was summarized by Wenner (1999). Conversion of scale to otolith ages was covered in the 30th SARC.

*H. The age-composition of the catch may not be reliable (e.g., no validation of annuli in otolith based ages, in scale based ages, or in the relationship of otolith to scale based); therefore, the results from the ADAPT and subsequent analyses dependent upon these results are suspect, as VPA assumes no errors in catch-at-age.*

**TC Agrees**

This applies primarily to VPA. Index driven and biomass dynamic model assessments using aggregated landings provided similar trends; the latter were presented to the Panel, but not mentioned in their review.

*I. Spatial analysis of fishery and survey data would help to determine what the portions of the resource the data represent.*

**TC Agrees**

Detailed spatial analysis has not been conducted on an age-structured or aggregated basis. TC may not have spatial analysis (GIS) expertise.

*J. No information from fishery independent surveys on changes in growth was presented.*

**TC Agrees**

Growth estimates could be made for some years and surveys with extended age structure and otolith collections (DE and NJ). Bias could result if large weakfish avoid trawls or if growth variation reflects stock structure.

**Peer Review Section 2. Review adequacy and uncertainty of fishery-independent and dependent indices of relative abundance.**

*K. The TC believed that ADAPT would be able to sort out the different survey variances; however, ADAPT is not capable of doing so.*

**TC Disagrees**

This was not one of our beliefs. This was the configuration of the SARC 30 approved model. We ran multiple index configurations of VPA, untuned VPA, and biomass dynamic models (Part 1, pages 27-28 & a 15 min presentation to the panel), to try and understand survey contributions.

*L. Both the TC and Panel felt the NEFSC fall inshore survey had the broadest geographic coverage of available surveys, could be used to monitor long-term trends of relative abundance, and tracked some cohorts well.*

**TC Disagrees**

While the TC would agree that the NEFSC survey has good geographic coverage and adequate precision, we have found it to be unsuitable as an index of exploitable weakfish abundance or biomass for the following reasons:

1. Cohort catch curves of NEFSC survey indicate spontaneous generation (year-class increases in abundance) in some cases.
2. Too few weakfish of sizes of interest to fishery were present in this survey after minimum size was raised in mid-1990s (fishery selectivity changed and NEFSC no longer sampled relevant sizes). PSD (length-frequency) analysis indicated proportion 13 inches+ in NEFSC was too small to estimate reliably (Uphoff 2004). NJ and DE sample sizes provide reliable, precise PSD estimates, and are well correlated.
3. Use of NEFSC index leads to conclusion of high stock status, contradicts other indices and landings.
4. NEFSC index significantly correlated with NJ and marginally with DE. MRFSS and NEFSC not correlated (r = 0.03; J. Uphoff, recent analysis).

*M. Each fishery dependent index [in this case, the MRFSS aggregated biomass index] has nuances with catchability (i.e., technological changes) which were not discussed. The mid-Atlantic fleet appears not to reflect abundance. For example, there is a concern that a proportion of the stock migrates out of the mid-Atlantic area and that proportion varies annually, which would affect the catchability of the mid-Atlantic private boat fleet.*

*N. This [private boat] fleet historically accounted for a small component of total catch (11% in 1989, 12% in 1990), but accounts for more than 50% in recent years and does not account for trends in abundance outside the fished area (North, South, and offshore).*

**TC Disagrees with M and N.**

This is a strong statement that can't be supported without an independent estimate of abundance and movement.

During the Weakfish TC meeting in Providence, V. Crecco was asked to comment on the contention by the Weakfish Peer Review Committee that the private boat recreational catches have comprised an ever increasing proportion of the total coast-wide weakfish harvest from 1989 to 2005. Based on these findings, the Review Committee concluded that the Mid Atlantic private boat CPUE was an uninformative index of coast-wide weakfish abundance.

V. Crecco examined the inputs (total recreational catch and effort) in the Mid Atlantic private boat indices from 1989 to 2005 based on the MRFSS database. There appears to be major confusion among the Reviewers regarding their definition of "landings" and "catches" in their assertion about the private boat index. The Reviewers used column 2 (total coast-wide landings and discard losses) and column 4 (Mid Atlantic private boat catches mt) in Part 1, Table 10, page 70 to generate ratios of private boat catches to total coast-wide landings from 1989 to 2005. Unfortunately for the Reviewers, the data in col 4 in Table 10 are recreational total catches including weakfish released alive (A, B1 and B2) in the Mid Atlantic private boat fishery. These recreational catch data are not directly comparable with the coast-wide landings (commercial and recreational harvest) plus discard <u>losses</u> (20% of recreational releases and all commercial gill net and trawl releases) in column 2. As a result, the apparent rise in the percentage of private boat catches to total landings from 1989 to 2005 is baseless because the units of catch and harvest are incompatible. If you compare the Mid Atlantic private boat harvest (A and B1) to the total coast-wide harvest, the percentage composition of the private boat harvest varies without trend from 1989 to 2005 with a long-term mean of 18%. The imposition of coast-wide minimum size limits and creel limits in 1994 on the recreational fisheries generated a sharp rise in the magnitude of B2 catches (releases) in the Mid Atlantic private boat fishery from 1994 to 2005. Therefore, the argument put forth by the Reviewers regarding the reliability of the Mid Atlantic private boat index is an artifact of a faulty comparison of apples (coast-wide landings) and oranges (private boat catches).

The 40th SARC recommended development of a recreational CPUE index. The TC developed the MRFSS index as a substitute for the NEFSC survey. Substitution of MRFSS for NEFSC indicates a decline to low status instead of an increase to high status indicated by the NEFSC survey. These conflicting trends clearly required a choice between these indices.

Correlation analysis indicates that MRFSS, DE, and NJ biomass indices are significantly correlated. MRFSS and DE indices are significantly correlated with total landings (J Uphoff, recent analysis). MRFSS CPUE well correlated with DE PSD (long-term indicator of status).

Analyses were conducted with multiple indices and this was indicated to the panel. They were available for review upon request. They were not included because of space limitations and information overload.

MRFSS index coverage is broad (NY-VA) and constitutes the core area where weakfish are likely to be a sought gamefish rather than an angler's afterthought. The MRFSS Index includes offshore catches. Minor sportfisheries exist to the north and south of the index region. Northern region (north of New York) MRFSS catch estimates average 0.3% of total catch and southern region (NC-FL) averages 14%. Recreational catches in south have increased, but most have been in NC. Commercial catches in NC have fallen. If weakfish distribution were shifting, wouldn't both sectors in NC reflect an increase? Omitting south catches (NC-FL recreational and portion of NC commercial) from the coastal Steele Henderson model (hence, a mid- to north Atlantic assessment) produces results with minimal differences.

Assessment of index catchability (NEFSC, NJ, DE, MRFSS) and converged VPA biomass during 1982-1993 indicated MRFSS catchability was most consistent (Part 2, page 12). Survey catchabilities were much more variable and inverse relationships with biomass were suggested. NEFSC survey had the worst attributes in catchability. If converged VPA is considered a reasonable estimate of biomass, than MRFSS index q varied up to 3x's during this period, while NEFSC survey q's varied up to 28x's. Trawl survey q must be quite variable too, given the sawtooth pattern exhibited in NJ and NEFSC indices.

Changes in catchability over the recent decade were not described in Parts 1 or 2, however. Evidence for MRFSS index q to change is supported by estimating relative q (MRFSS index divided by DE or NJ index during 1989-2003 (biomass units for all; this was estimated for the panel at the review). MRFSS catchability rose from and fell to baseline during 1997-2000. Using NJ and DE survey biomass indices as tuning could ameliorate this.

**Peer Review Section 3. Review the appropriateness of constant and variable natural mortality (M) estimates in the assessment.**

*O. The sampled age-structure indicates extraordinarily high Z estimates during periods of low catch, suggesting that M rates are high. However, there are two additional reasons that Z could be inflated, 1) older ages are truncated by the selectivity of the gear and 2) catches of older fish in areas where fish are not sampled (e.g., New Jersey).*

**TC Agrees**

Selectivity and catchability can be confounded with M in age structured assessments.

The Z's have increased in recent years. These phenomena (selectivity and q) would have had to only increased greatly in recent years after imposition of substantial conservation measures (minimum mesh sizes, increased length limits, seasons, NC area closures).

We did not have samples from NJ and NY during early and late in the time-series (when stock was relatively high), so this bias should be the same both periods of the assessment (extended age and size structure were present). Age-structured and age-aggregated assessments detected much higher F's during the early period than recent years.

The mixed nature of the commercial fishery off NC in winter and its migration down the coast through MD and VA in fall does provide an opportunity to sample these "missing" fish.

*P. The TC makes the case for increasing Z based on the ADAPT Run #20 (the preferred run from Stock Assessment Report). All other ADAPT analyses indicate that total mortality is decreasing. The distinguishing feature of Run #20 is that it is tuned solely with the recreational CPUE from the mid-Atlantic private boats. All of the subsequent analyses were dependent upon the results of Run #20.*

**TC Agrees**

In ADAPT runs other than #20 (tuned to trawl surveys), F decreases to an unrealistically low level and the stock biomass increases 3x's beyond anything estimated previously and shows no sign of decreasing. It implies decreased catches because fishers are disinterested or weakfish have become more devious. Run 20 retrospective bias was low compared to trawl survey tuned runs. The 40$^{th}$ SARC did not consider runs with trawl surveys credible.

The 40$^{th}$ SARC panel encouraged development of an MRFSS index.

At least three other ASMFC assessments feature MRFSS indices: Atlantic croaker, striped bass and bluefish.

*Q. The TC tried to explain the increase in Z as increased predation mortality by striped bass using a production model coupled with a Type III functional response. No statistics were presented that allowed the Panel to evaluate the Steele-Henderson model relative to models that assume constant M.*

**TC Disagrees**

Part 2, page 17: SSQ, $r^2$, bootstrapping, and Figure 26 (observed and predicted points for models with and without predation term). Biomass dynamic models without predation based on surveys were presented in Part 1, pages 25-29. Also part of slide presentation. Part 1, pages 35, 41-42, Tables 15-21, included parameter SE, SSQ, $R^2$, and residual patterns.

*R. The evidence for striped bass predation on exploitable sized weakfish is weak. The Steele-Henderson model is inappropriate for the interactions among striped bass, weakfish, and menhaden, because it assumes that predation occurs only on fish that are fully vulnerable to the fishing gear and ignores predation on smaller fish.*

**TC Disagrees**

The panel was presented with this summary of the reach of statistical analyses and Steele and Henderson model:

- **High-low weakfish biomass domains evident long-term (statistical).**
- **Menhaden has large influence over long-term domains (statistical).**
- **Now in low domain – cutting F may not allow for recovery because bass M high (Steele and Henderson).**
- **Bass-weakfish model (Steele and Henderson) applies to low domain.**

The Steele and Henderson (S-H) model was not developed to fully explain the triangular food web (menhaden, bass, weakfish) presented. It was used to explore depensatory mortality caused by striped bass during the most recent two decades of declining and low forage abundance. The combination of statistical analyses and S-H model explored this food web hypothesis. This combined approach was explicit in the Part 2 introduction of the scope of the analyses. The model is appropriate for the exploration, but it will not supply a full explanation. It does account for 78% of variation in the MRFSS index since 1981.

This is something we may not have explicitly talked about with the Panel, but the MRFSS catch index is composed of some weakfish that are small. MRFSS harvest length-frequencies contain some weakfish as small as 5 inches and 8-10 inch fish are not uncommon. The catch (releases) will be comprised of an even larger fraction of small weakfish vulnerable to predation. The MRFSS index, based on catch, is not as

vulnerable to selection changes as a harvest-based index or a survey index, such as the NEFSC fall survey, where a very large fraction of fish present in the survey went from legal to sublegal after regulations were imposed.

Recent diet analyses of large striped bass collected off Cape Hatteras (2005) and Virginia Beach (2006) in fall and winter by Dr Anthony Overton (East Carolina University) indicate a fairly steady prey-predator length ratio (0.1-0.3) for striped bass, before it tapers of to 0.45. In other words, a 900-1100 mm striped bass can readily eat weakfish that would be legal-sized. Smaller weakfish (8 inches) would be fairly vulnerable to striped bass as small as 500 mm. Weakfish comprised 5% of diets by weight in this study, the highest percentage I know of. The Steele and Henderson model in Part 2 indicates that a decline in weakfish would be induced by striped bass even though weakfish are only a minor part of the diet (1-2% of total when compared to bioenergetics estimates of bass total consumption). This is consistent with the importance of weakfish in bass diet studies; Part 2 page 23.

Consumption of weakfish by striped bass associated with the model (0.09-0.10 kg weakfish per kg striped bass) is very modest compared to total consumption of fish by bioenergetics (4-7 kg of fish per kg of striped bass) and is consistent with mid-Atlantic diet studies.

The Panel's interpretation that the model can only be applied to exploitable weakfish eaten by striped bass is not correct. A production model subsumes recruitment, growth, and natural mortality into a single function. The effects of predation may not be evenly applied across the three sub-functions and the model is just going to calculate a general loss associated with a predator trend. See Part 2, page 22.

Analysis of predation on small weakfish (relative Z) was presented in Part 1, pages 32-34. The rise in relative Z was consistent with M associated with bass in the predator-prey model.

*S. A more rigorous approach to considering multispecies interactions would be to consider a precise hypothesis and incorporate the appropriate process in the population model.*

**TC Disagrees**

<u>We operated from very specific hypotheses and used methods suited to modest data sets.</u> The approach suggested by the Panel would likely lead to an overparameterized model. We developed the hypothesis that M has been changing for weakfish and that it is the primary driver behind the recent crash as a specific alternative, nonfishing mortality hypothesis explaining an aborted weakfish recovery. We investigated specific hypotheses that weakfish biomass dynamics, growth, and survival were negatively affected by striped

bass and exacerbated by depleted forage. We postulated and eliminated other candidate predator/competitors and environmental factors (water temperature and North Atlantic Oscillation index) to see how easily "spurious" hypotheses could be confirmed. See the Introduction of Part 2 and Part 1, page 35 for further specifics.

*T. For example, if the precise hypothesis is predation of age-0 and age-1 weakfish by striped bass, then a stock recruitment function with a predation term would be appropriate.*

**TC Disagrees**

Stock-recruitment analysis requires a good underlying assessment. Errors in the estimation of SSB can produce a "relationship" that may not exist. If you start with a single species assessment under an assumption of constant M when M isn't constant, you will end up with a misleading relationship. Stock-recruitment relationships are seldom well estimated or can appear to be when they are, in fact, seriously biased.

*U. If M has increased over time, then the corresponding estimate of $F_{msy}$ would be greater than the estimate of $F_{msy}$ that assumes constant M. If M is truly increasing, but we assume that it is constant, then we would advise for future F estimates that are less than the true $F_{msy}$. Conversely, if M is truly constant and we assume that it is increasing, we would recommend that future F estimates that are greater than $F_{msy}$. Therefore, assuming constant M is more risk averse than assuming an increase in M.*

**TC Disagrees**

Constant M was a very risk prone assumption in most model configurations. Most VPA runs (except run 20 with MRFSS tuning) and standard Schaefer models without predation did not indicate that F was at anything that would have caused concern.

Only VPA run 20 under constant M=0.25, rescaled F analysis based on run 20 that allowed for estimation of varying M, or biomass dynamic models with a bass predation component indicated otherwise. VPA run 20 under constant M=0.25would indicate that large cuts in F were necessary and would lead to recovery. Rescaled F analysis and bass predation models indicated that M was much higher than F and recovery was unlikely by cutting F without a drop in M.

Equilibrium MSY limit reference points estimated from the S-H model (Steele and Henderson striped bass-weakfish predator-prey model; Part 2, page 21), indicated that F had been below the equilibrium $F_{msy}$ limit for nearly a decade, but biomass had fallen well below the $B_{msy}$ limit in the last several years. By 2003, rising $M_b$ (bass-related natural mortality) ate away at the amount of F that represented a level of "safe" fishing; residual production after bass predation ($r - M_b$) fell from 0.66 in 2001 to 0.08 in 2003. Even though F fell from 0.50

during 2000-2002 to 0.39 in 2003, the amount of residual productivity after bass predation and fishing ($r - M_b - F$) went from positive to negative (0.16 to -0.31) during 2000-2003. By 2003, completely cutting F to compensate for high $M_b$ would result in slow biomass growth at best.

**Peer Review Section 4. Review the estimates of fishing mortality (F), spawning stock biomass, and total stock biomass for 1981-2004, and characterize the uncertainty of these estimates.**

*V. There is some optimism for weakfish stock status, as recruitment has not declined in any portion of the range. Despite our uncertainty in stock productivity there is no apparent decrease in recruitment. In fact, evidence suggests that there have been recent increases in recruitment over the last 15 years.*

**TC Disagrees**

This is true for the grand mean of multiple surveys. However, in the last 3 years (2000-2003) in the north (RI-DE) and south (MD-NC) there is some evidence of regional declines and a more chaotic picture than indicated by the grand mean. In the north, 2 state indices have declined to below average, 1 is steady at below average relative abundance, and 2 have increased (1 to above average and 1 to average). In the south, 3 have declined below average, and 1 has increased to above average. Age 0 sized weakfish relative abundance in SEAMAP and NEFSC is above average.

*W. The Panel is uncertain of the direction of Z, F, and M estimates, and, as a result, it is difficult to choose among alternative explanations of observed changes.*

**TC Disagrees**

The TC unanimously still supports the five points of agreement reached in February 2005 regarding weakfish stock status. The five points were

- **stock is in decline;**
- **total mortality is increasing;**
- **not much evidence of overfishing;**
- **something other than F is going on; and**
- **strong circumstantial evidence of increasing M.**

Stock assessment can provide support for decision making by describing possible alternative states of nature and their consequences to management (See Part 1,Tables 1A and 1B, pages 54-55) . This is what the TC sought to do with the divergent signals it obtained after extensive analysis. There are uncertainties and different interpretations associated with the quality of fisheries data, analysis, and interpretation, as evidenced between the amount of disagreement between the TC and Panel. There clearly are risks associated with

paring away too much information as the Panel has done – there is simply nothing left as a basis for making decisions.

In a decision analysis context, it can be very important to carry a hypothesis through the assessment and examine its management implications even if it has a low probability of being correct. A hypothesis that is rejected as being improbable based on usual scientific criteria should remain in a decision analysis if it has particularly important management implications. The implications of increasing M have been demonstrated by the TC. Simply presuming that ceasing exploitation on an overfished stock has to result in recovery ignores the uncertainty imposed by ecological systems. Weakfish may or may not recover with more regulation in a world where food webs exist.

The Panel's alternative to a decline because of rising M is massive discarding arising from Amendments 2-4. In this case, weakfish regulations created a huge discarding problem (manifold greater than landings) that cannot be solved by only regulating the weakfish fishery. This hypothetical problem, which cannot be confirmed with our current discard data and methodology, likely requires keeping major mobile finfish fleets of the mid-Atlantic from fishing for any species inshore. It is interesting to note that the Panel did not indicate or suggest that directed overfishing was occurring.

Finally, there is a body of models in this assessment, based on accepted conventions, that indicates things are going swimmingly and nothing further needs to be done. They are not necessarily reflective of indices, landings, or fishers' experience over much of the mid-Atlantic. These models require application of pretzel logic to be acceptable - no one really wants to catch weakfish anymore.

**Executive Summary: How Much Additional Discarding and Under-Reporting is Needed to Cause the Decline in Weakfish?**

Jim Uphoff

June 20, 2006

The Weakfish Peer Review panel suggested that a steep rise in unreported commercial discards of weakfish after 1995 could have created the recent weakfish stock collapse in lieu of our hypothesis of a rise in natural mortality. As a response, I fit a biomass dynamic model to three biomass indices, harvest, estimated discards, and an additional loss term ($L_F$) mimicking various commercial bycatch scenarios (constant function of harvest plus discards, two increasing functions of time, or an inverse function of biomass). Additional losses were imposed after 1995 to reflect regulatory discards. Results were contrasted with those of a striped bass–weakfish predator-prey model and a biomass dynamic model without $L_F$. Additional losses from simulated bycatch scenarios or striped bass predation improved fit over the unaltered model (Figure 1). Median $L_F$ estimates during 1996-2003 (6,100-6,800 mt) were greater than median bycatch (1,700 mt) and harvest (4,400 mt). By 2003, $L_F$ estimates were 3-13 times discards used in the assessment depending on how trends in $L_F$ were simulated (Figure 2). There is no evidence available thus far that points toward any Atlantic coast fishery capable of generating 3,000-13,000 mt of additional unreported weakfish discards. The results of these bycatch scenarios taken at face value suggest that weakfish regulations created this massive boost in discards. Thus, implementation of further conservation measures short of a coast-wide moratorium on all Atlantic coast fisheries will not minimize this discard problem.

Rising natural mortality provided a reasonable alternative to enormous undetected discards. Estimated losses of weakfish to modeled striped bass predation fell just below upper range of commercial bycatch scenarios. Striped bass biomass has increased approximately 20-fold since 1981 and modeling indicated little change in weakfish consumed per unit area per unit time (depensatory mortality). This situation is analogous to a fishery able to apply more effort while maintaining catch efficiency. Consumption of weakfish by striped bass associated with the model (0.09-0.10 kg weakfish per kg striped bass) is very modest compared to total consumption of fish by bioenergetics (4-7 kg of fish per kg of striped bass) and is consistent with mid-Atlantic diet studies.

Figure 1. Fit of biomass dynamic model using original harvest + discards with and without additional loss functions. WRI = MRFSS private boat catch per trip index; NJ and DE are trawl survey indices. Loss functions depict striped bass predation, losses as an inverse function of weakfish biomass, quadratic or linear functions of time, and as a constant function of the sum of harvest and estimated discards.

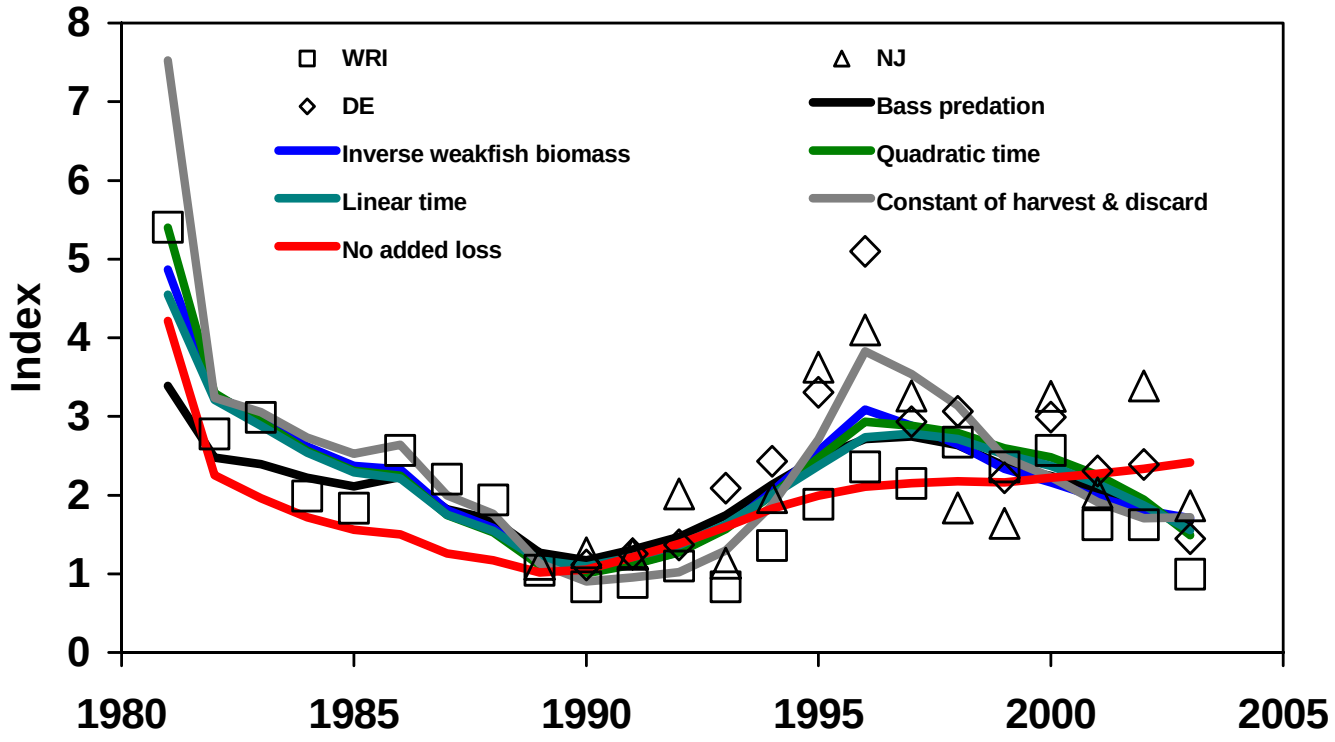
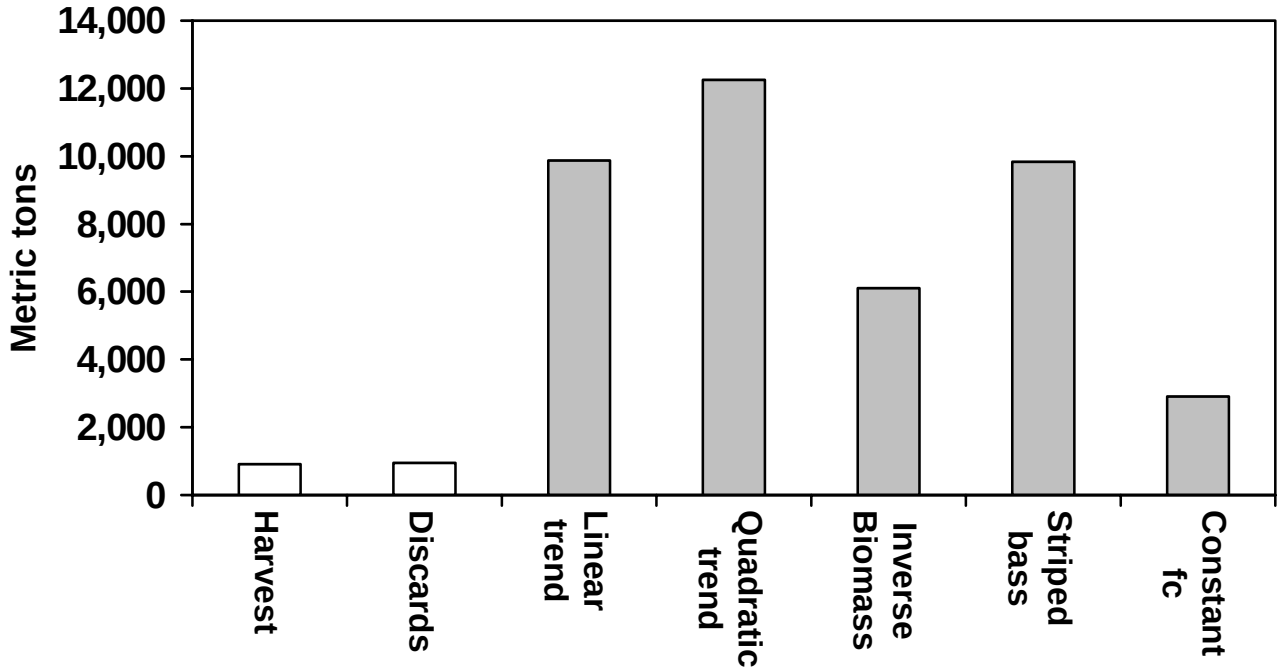



Figure 2. Metric tons of additional losses in 2003 from different loss scenarios contrasted with commercial harvest and discard estimates



**Executive Summary: Estimating At-Sea discards of weakfish using NEFSC Observer database**

Weakfish Technical Committee

July 2006

This is a brief summary of *Estimating At-Sea discards of weakfish using NEFSC Observer database*, a report prepared by Janaka de Silva (FL) in 2004 for the Weakfish Technical Committee. This report provided the technical basis for discard estimates used in the recent stock assessment.

Estimates of commercial discards were developed from 1994-2003 NMFS at sea observer data. The database contained information on weakfish discards, target species catches, estimates of landings of species kept on the haul, and length data of both discards and fish kept. We only evaluated hauls that were completely sampled for discards. During 1994-2003, discard data were primarily available for gillnets (287 trips and 615 hauls; 89% landed in Virginia, North Carolina or New Jersey) and otter trawls (196 trips and 519 hauls; 41% landed in Maryland and 49% in New Jersey, New York, or Rhode Island.). The annual number of gillnet trips where weakfish discards were observed ranged from 5 to 68. The numbers of otter trawl trips where weakfish discards were observed ranged from 4 to 45.

We developed estimates of weakfish discards using annual (1994-2003) discard ratios (weakfish : target species) and NMFS commercial landings of a suite of target species. The ratio of at sea observations of weight or number of discarded weakfish to pounds of harvested target species by gear (trawl and gill net) was scaled up to total discard estimates based on total landings of the target species. Discards were subdivided into regulatory and market discards. Identification of target species was only based on complete trips and hauls where weakfish discards were observed. Target species were weakfish, longfin squid, Atlantic croaker, butterfish, summer flounder, Atlantic menhaden, spiny dogfish, spot, and bluefish. We assumed that gear-specific relationships among the target species in the data set reflected the entire fishery.

Slightly more than half of ratio estimates were significantly different from zero. Ratio estimators work best when there is evidence of a positive linear relationship between the response and explanatory variable. Total discard estimates presented in this report included estimates from target species where there was not evidence of a strong linear relationship between weakfish discards and the target species we examined.

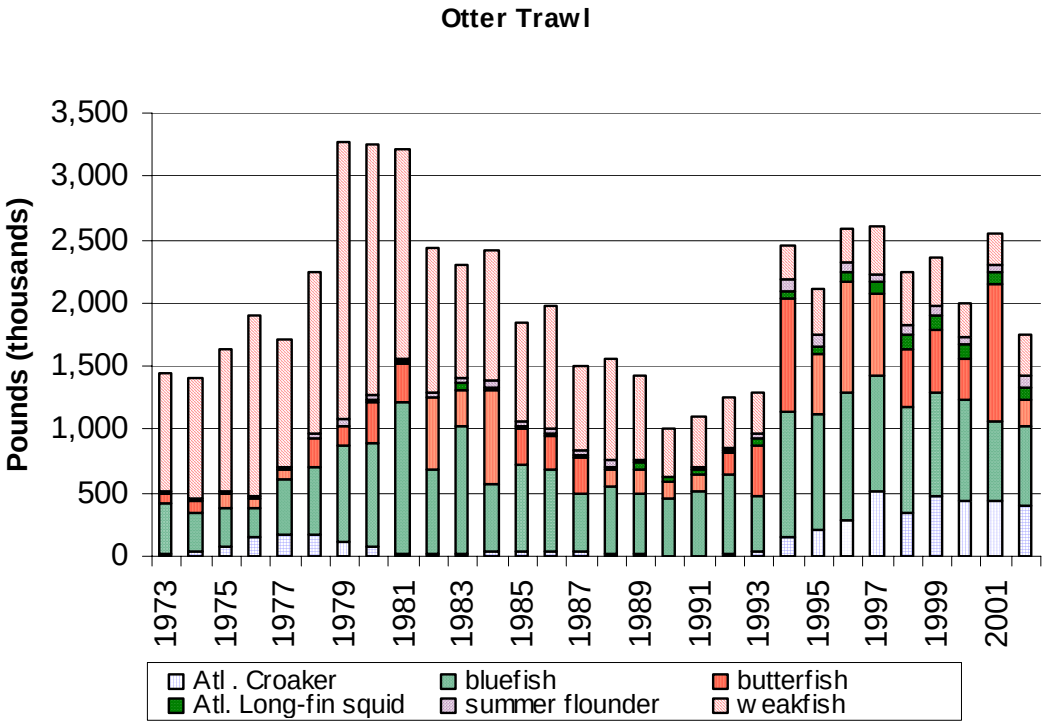
During 1973-1992, coast-wide commercial fishing regulations on weakfish were not in place. Market-related discard ratios were used to estimate weakfish discards during 1973-1992. In 1993, New Jersey and Delaware enacted weakfish regulations that may have lead to non-market discarding and the total discard ratio was used for these states. For all other states, discard estimates for 1993 were based on the non-regulatory discard ratios. During 1994-2002, total discard ratios were used to estimate weakfish discards for all states. Commercial discard data was not available for 2003 when these estimates were formulated for the assessment and we averaged the commercial discard estimates for 2001 and 2002.

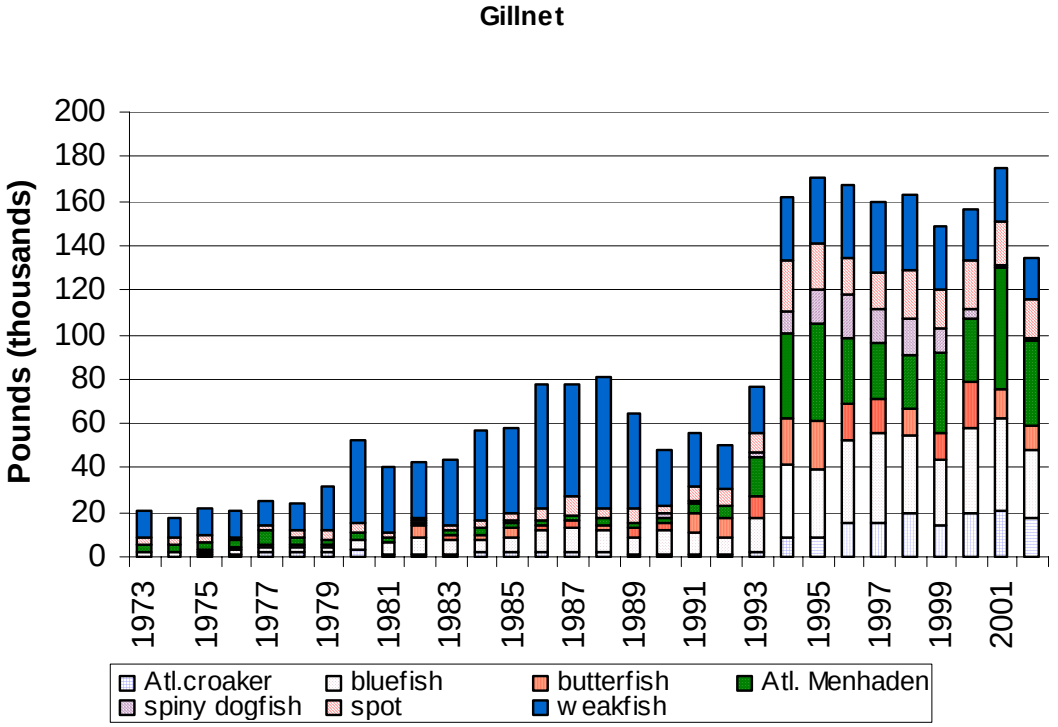
We considered all estimated commercial discards to have died in the stock assessment. Weakfish discards for the mid-Atlantic were predominantly associated with otter trawls (Figure 1). Trends in otter trawl weakfish discards for the mid-Atlantic show a cyclical trend, with peaks around the late 1970's (~ 3 million pounds) declining to a low of around 1 million pounds in 1990, and stabilizing around 2.5 million pounds in recent years. Trawl fisheries for Atlantic croaker, summer flounder, bluefish, butterfish, and weakfish account for most discards once regulations were imposed (since mid-1990s). For mid-Atlantic gillnets, discards rose from 50,000-80,000 pounds prior to 1994 to 150,000-160,000 pounds during 1994-2001. Estimated discards fell to around 120,000 pounds in 2002. Gill net discards are now mostly from the Atlantic croaker, Atlantic menhaden, spot, butterfish, and weakfish fisheries; discards from the spiny dogfish fishery no longer appear in our estimates (Figure 1).

We also developed discard estimators using a regression approach, but found the models to be of poor quality. While effort (trip) based estimators could be developed, the corresponding effort information on the target species in the fishery are only available for some states and in certain years.

Most commercial fisheries were eliminated from the South Atlantic by the mid-1990s. Weakfish discard estimates for the South Atlantic were low and of poor quality because they were based on estimates from the mid-Atlantic. They were not included in the assessment.

**Figure 1. Estimated weight of weakfish discarded by mid-Atlantic otter trawl and gill net fisheries**



# The weakfish population structure along the Atlantic Coast: a literature review

A report to the Atlantic States Marine Fisheries Commission's Weakfish Technical Committee

By

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## Weakfish population structure

This note summarizes available information on weakfish population structure, part of which (especially the tagging outputs, meristic, morphological and life history characters of weakfish inhabiting the Mid-Atlantic) was reviewed by Mercer (1985, 1989). Weakfish, *Cynoscion regalis*, occur along the Atlantic coast of the United States of America from eastern Florida to Massachusetts, but are most abundant between New York and North Carolina (Mercer 1989). Weakfish stock assessments and related fishery management plans have been configured and implemented on the basis of a single, panmictic weakfish population (e.g., Mercer 1985, Anon. 2002).

Investigations of weakfish population structure along the US Atlantic coast have been undertaken through tagging, meristic, morphological, life history, genetic and otolith chemistry studies (Table 1). The conclusions reached are conflicting. While Crawford et al (1988), Graves et al. (1992) and Cordes & Graves (2003) did not detect genetic differentiation within the weakfish population, Chapman et al. (unpublished report) found that weakfish are made up of a series of overlapping stocks, without complete panmixia. Non-genetic studies found evidence of existence of multiple weakfish sub-populations (e.g., Nesbit 1954; Shepherd & Grimes 1983, 1984; Scoles 1990) or important spatial structure of the weakfish population (Thorrold et al. 1998, 2001). Mark-recapture, meristic, morphological and life-history studies (e.g., review by Crawford et al. 1988) indicated that weakfish could be partitioned into sub-stocks, and assessed and managed on a regional basis.

Whether studies did or did not detect discrete weakfish populations, it is worth mentioning views expressed and observations made by authors which may have assessment and management implications:

- Although the weakfish population is genetically homogeneous throughout its area of distribution, it exhibits variations in the population parameters (i.e. growth, mortality and fecundity), upon which the ability of a population to sustain a harvest is largely dependent (…);

therefore, as a practical matter, it is probably best to manage weakfish as discrete northern and southern units, even though these units are not reproductively isolated (Crawford et al. 1988).

- The genetic homogeneity found within the weakfish population contrasts with the geographical (and likely eco-phenotypic) variations of morphological and life history characters reported in other studies (…). There is clearly some interdependence among areas as also supported by tagging data (…). To obtain a meaningful estimate of the magnitude of the interdependence between these areas would require an extensive, time-consuming and expensive tagging study. Until such information is available, it would be best to manage the weakfish resource as a single interdependent stock (Graves et al. 1992).
- Weakfish tagging data indicate that low levels of exchange occur between geographically distant populations of weakfish (e.g., Schwartz et al. 1979; Music & Pafford 1984; Bain et al. 1998).
- Our data show much more spatial structure than is currently assumed by fisheries managers, and it may be useful to consider weakfish population dynamics from a metapopulation perspective. However, these results do not contradict the genetic findings, because there are sufficient exchanges even among those estuaries with the highest levels of natal homing, to prevent genetic divergence (Thorrold et al. 2001).
- The results suggest that a cline of morphometric characters or substantial mixing among the morphological types occur intermediate in the range for weakfish. Moreover, weakfish samples collected from the winter fishery off NC suggest that 79.1% belong to the Long Island (med) reference sample and 20.9% to the Pamlico Sound reference sample. This finding suggests that a significant proportion of weakfish that overwinter off NC are similar in morphology to those found in Long Island Sound in spring… It appears likely that a majority of these fish are found in Delaware Bay and north in spring, and Chesapeake Bay and north in fall (Scoles 1990).
- Overall, there are two groups of weakfish (north and south) along the Atlantic coast. Still, due to the coastal nature and migratory behavior of the species, these groups are not genetically isolated. However, there is sufficient evidence that gene flow (and subsequent recruitment) is so limited that the southern aggregations make minimal contributions to northern populations (Chapman et al, unpublished report).

## Conclusion

Two main contrasting findings emerged from the literature on weakfish population structure along the Atlantic Coast. On the one hand, most genetic studies indicate that the weakfish population is genetically homogeneous. On the other, this population appears to be a mosaic of reproductively interdependent regional (even natal estuaries) sub-populations, as evidenced by meristic, morphological and life-history traits and, more importantly, by one genetic investigation and otolith chemistry studies.

On the basis of this information, pragmatism may dictate whether assessment and management strategies have to deal with a single unit-stock or separate unit-stocks (i.e., isolated, panmictic sub-populations, characterized by uniform growth, mortality, fecundity parameters, etc.). Gulland (1988) considered definition of a unit-stock an essentially operational matter, being tied to the models used, the questions asked, and information available. Stock structure is not considered in the striped bass assessment, even though stock structure is well defined.

It is worth keeping in mind that subdividing a stock (initially treated as a whole) into sub-stocks may meet homogeneity requirements, but it presents potential for not meeting the condition of isolation. One may expect that multi-stock assessment models will be complex and data-consuming, without any warranty of improvement in comparison with single- stock assessment models. In fact, the complications here potentially stem from (i) weakfish migration patterns (e.g., Mercer 1985, 1989), resulting in unknown mixing rates between various fishing locations, and (ii) the sequential nature of the exploitation along the weakfish migratory route.

**Technical Committee Position**

On June 20, 2006, the Weakfish Technical Committee (TC) reviewed this information on stock structure. Full agreement was reached on the following:

- Evidence of stock structure exists.
- Data is inadequate to define stock structure and there is enough potential mixing that pinpointing north/south (N/S) split is not possible at this time.
- If a north to mid-Atlantic subpopulation is in serious decline, this does not warrant a N/S split based on conservation concerns.
- The Board needs to clarify its reasoning for a N/S split.
- Does the Board want research recommendations on this from the TC?

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## Overview of the Weakfish Resource

By Jim Uphoff, ASMFC Weakfish Technical Committee Chair

Weakfish fisheries were subject to increasingly restrictive management during the early and mid-1990s and were thought to be on the path to recovery. Between 1999 and 2003, recreational and commercial landings of weakfish along the Atlantic coast plummeted to all-time lows while population estimates from traditional single species assessments reached all-time highs. This dichotomy of assessment results and fishery performance lead the Weakfish Technical Committee to consider less traditional assessment techniques.

A preponderance of evidence from these alternative approaches indicated that a large rise in natural mortality that started in the mid-1990s largely caused weakfish biomass and size structure to decline greatly by 2003. These declines could not be attributed to a slight rise in fishing mortality. When concerns about weakfish first arose during the late 1980s and early 1990s, estimates of fishing mortality were high. Conservative management measures were imposed beginning in the early 1990s and fishing mortality rates fell to modest levels after 1994. Biomass and size structure rebuilt for a time, but underwent a rapid decline after the late 1990s.

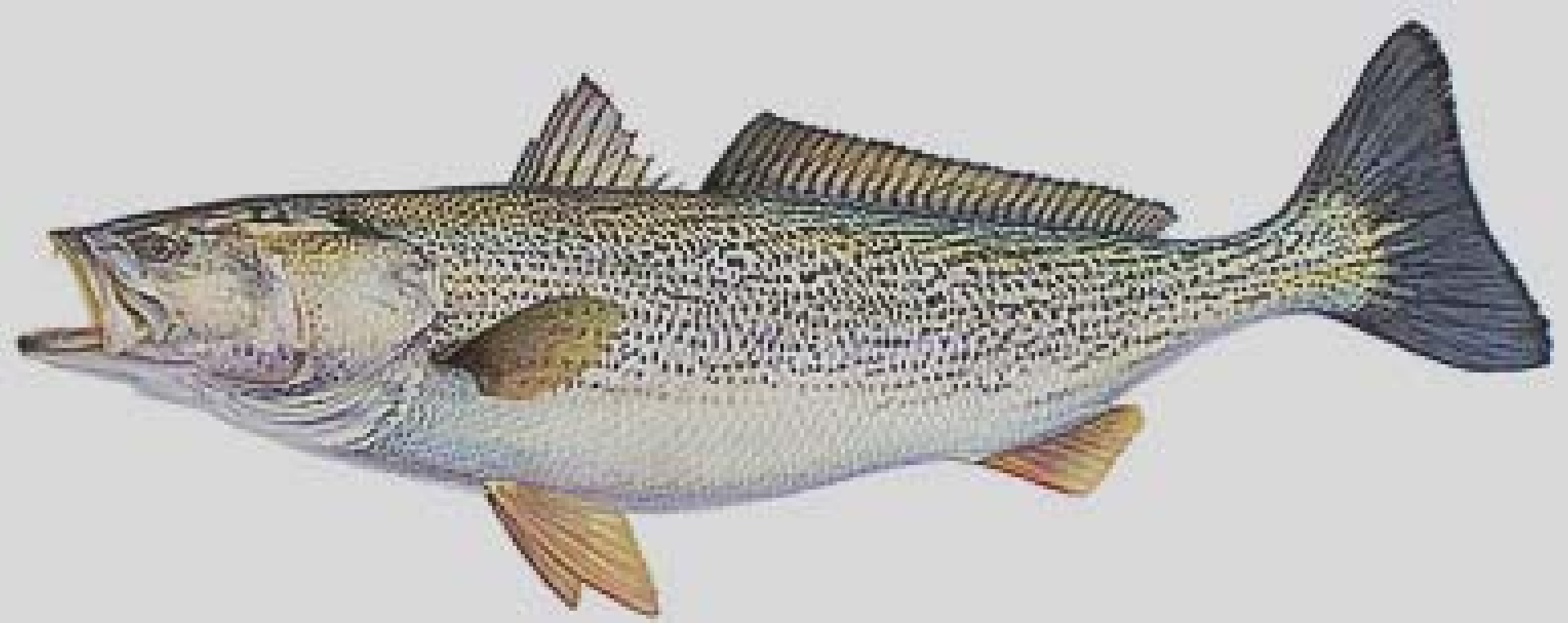
High and rising natural mortality does not provide managers much leverage for recovery by managing the weakfish fishery alone. However, projections indicated that cuts in fishing mortality will be needed for timely recovery if natural mortality declines.

In the past, we have presumed that ceasing exploitation on an overfished stock has to result in recovery. This presumption has ignored uncertainty imposed by ecological systems. The rapid decline in recent weakfish biomass and landings was reminiscent of rapid transitions between extended periods of high or low commercial landings dating back to the late 1920s. In theory, these rapid changes could reflect an underlying environmental driver whose effect has been accelerated by high fishing or predation rates.

The Technical Committee developed and tested specific hypotheses to evaluate candidate predator/competitors (striped bass, summer flounder, bluefish, spiny dogfish and Atlantic croaker), forage species (Atlantic menhaden, bay anchovy, and spot), climatic factors (water temperature and North Atlantic Oscillation index), high discard losses, and overfishing. Insufficient forage, especially Atlantic menhaden, and increased predation by striped bass have emerged from these analyses as leading candidates behind rising natural mortality. Contributions by remaining candidates or others may exist, but have not been detected or tested.

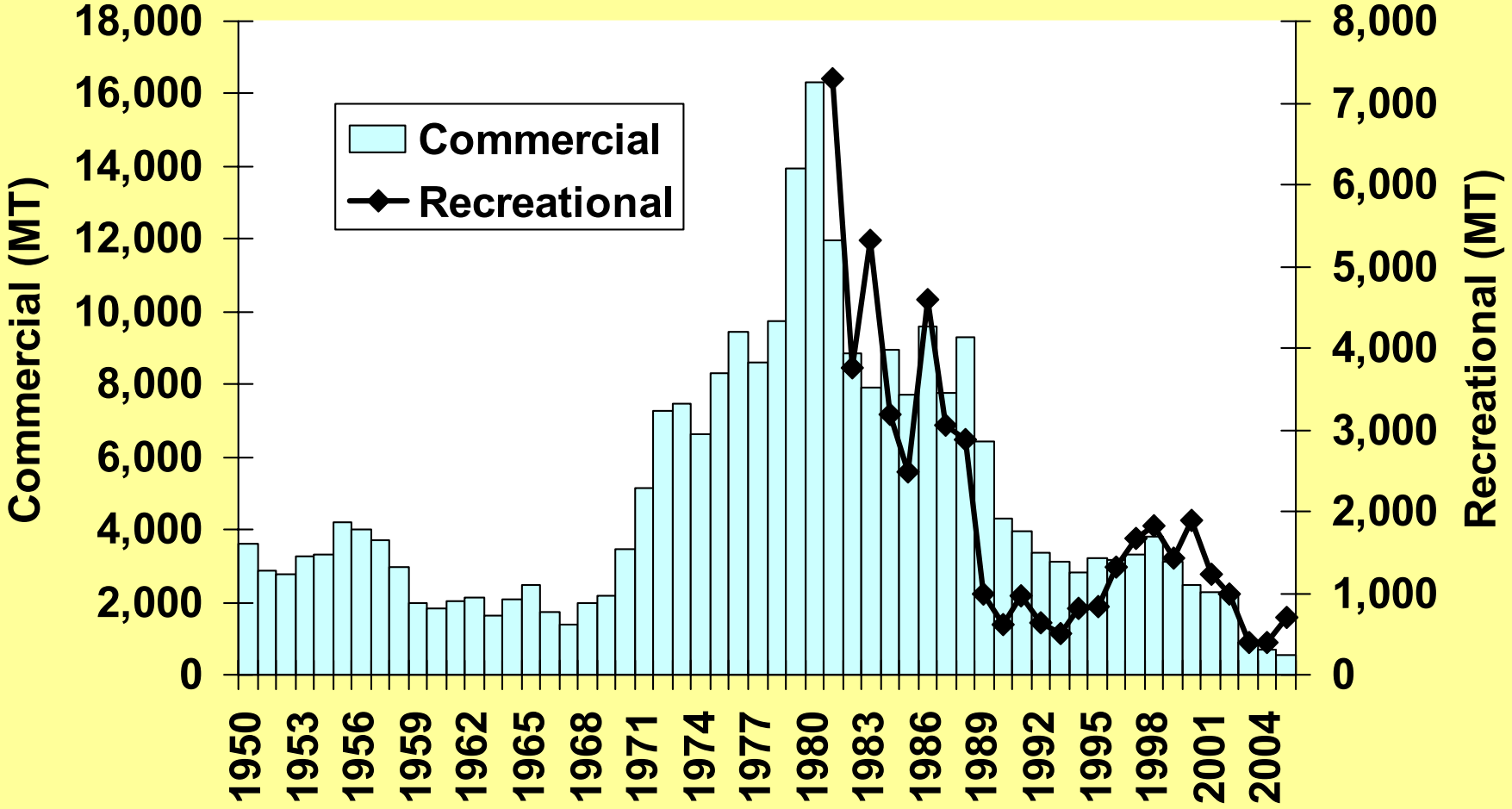
The following presentation was provided to the Commission's Weakfish Management Board at its August 2006 meeting. It was prepared to address questions raised by the Management Board and External Peer Review Panel regarding fishery status and possible next steps in the management program.

# What's Next with Weakfish?

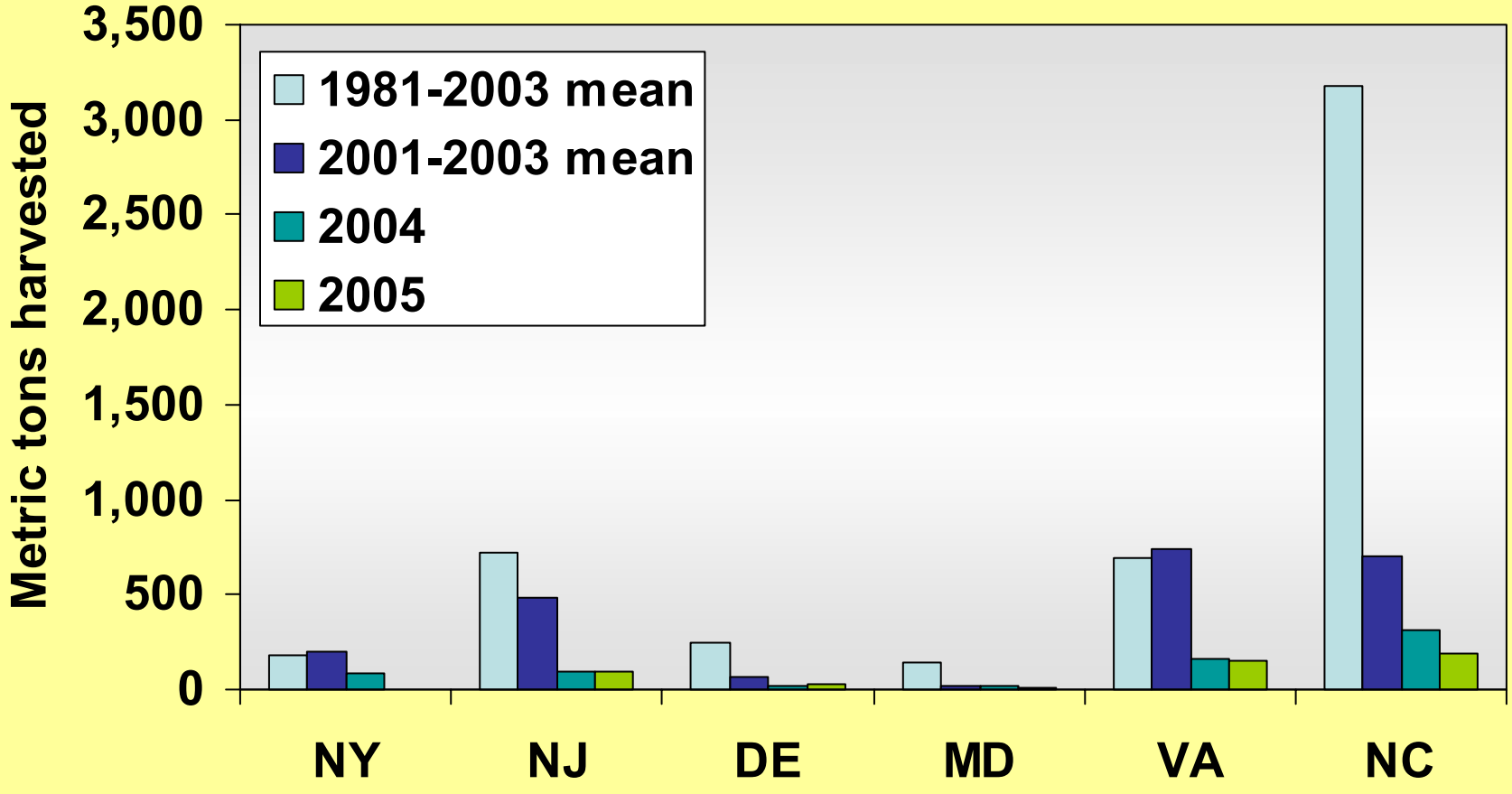


A Report of the Weakfish Technical Committee
- Fishery Status & Board Requests
August, 2006

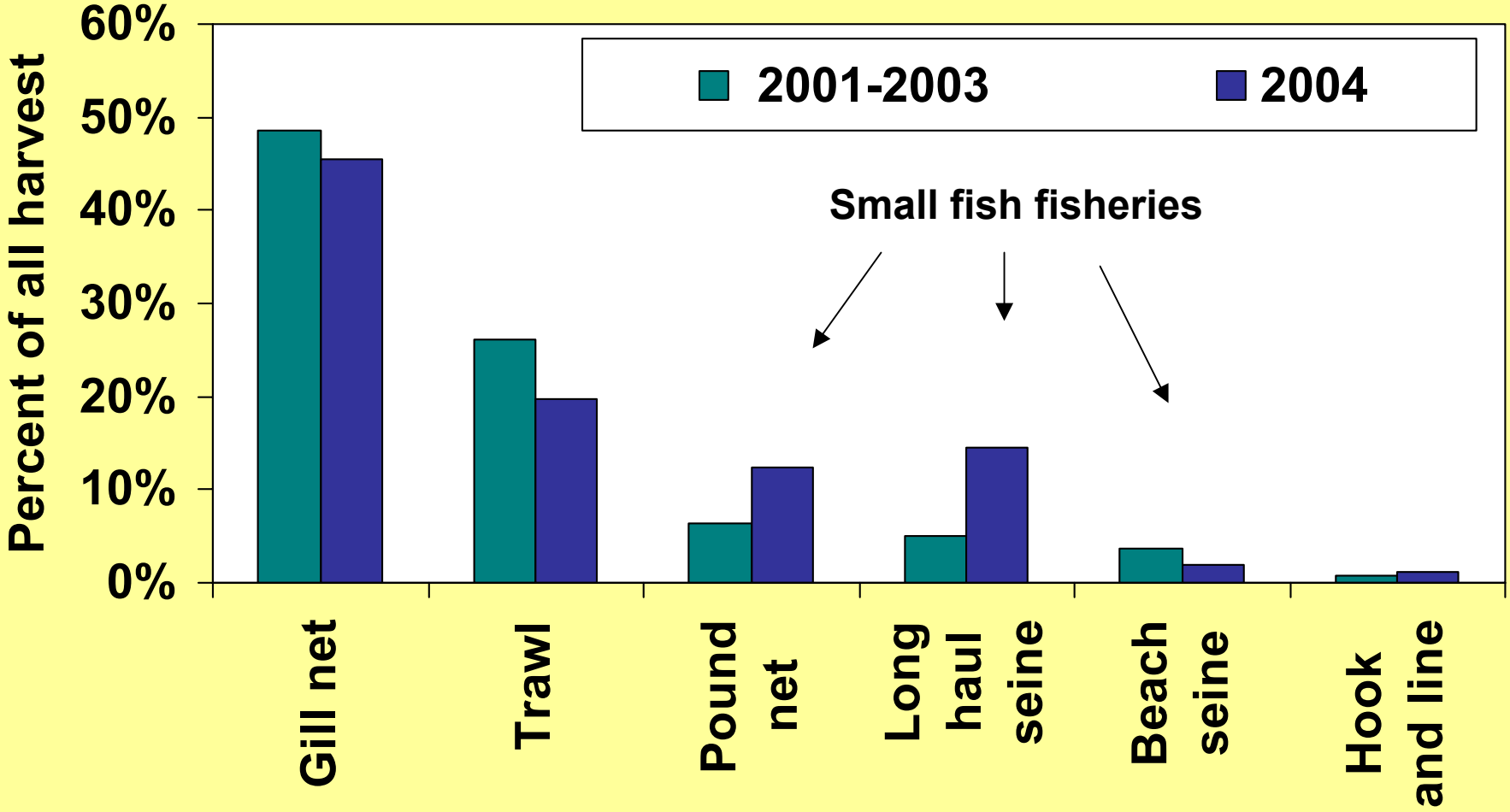
# Atlantic coast harvest of weakfish, 1950-2005



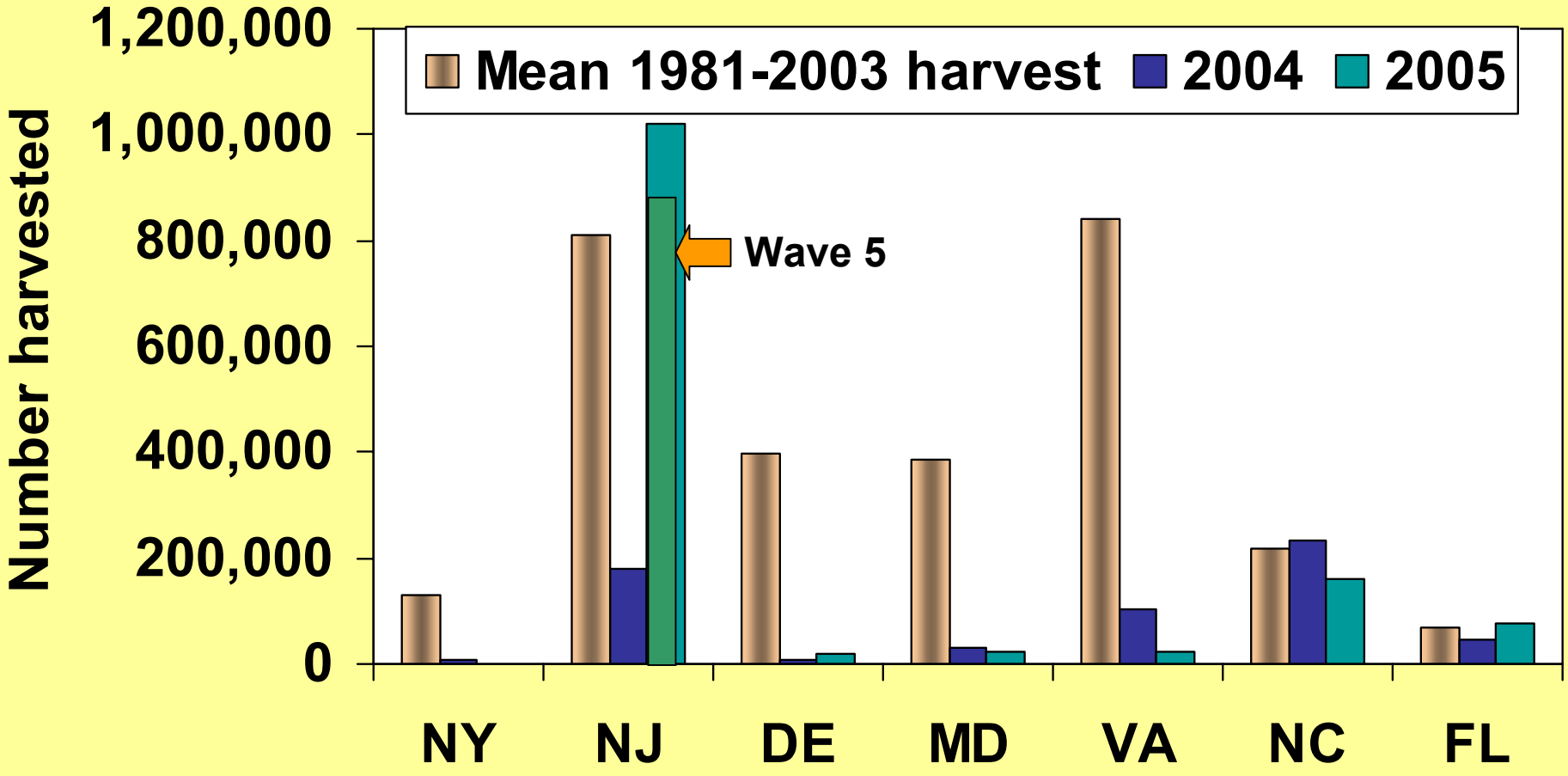
# Average commercial harvest by state during 1981-2003 and 2001-2003 vs 2004 and 2005 (incomplete)



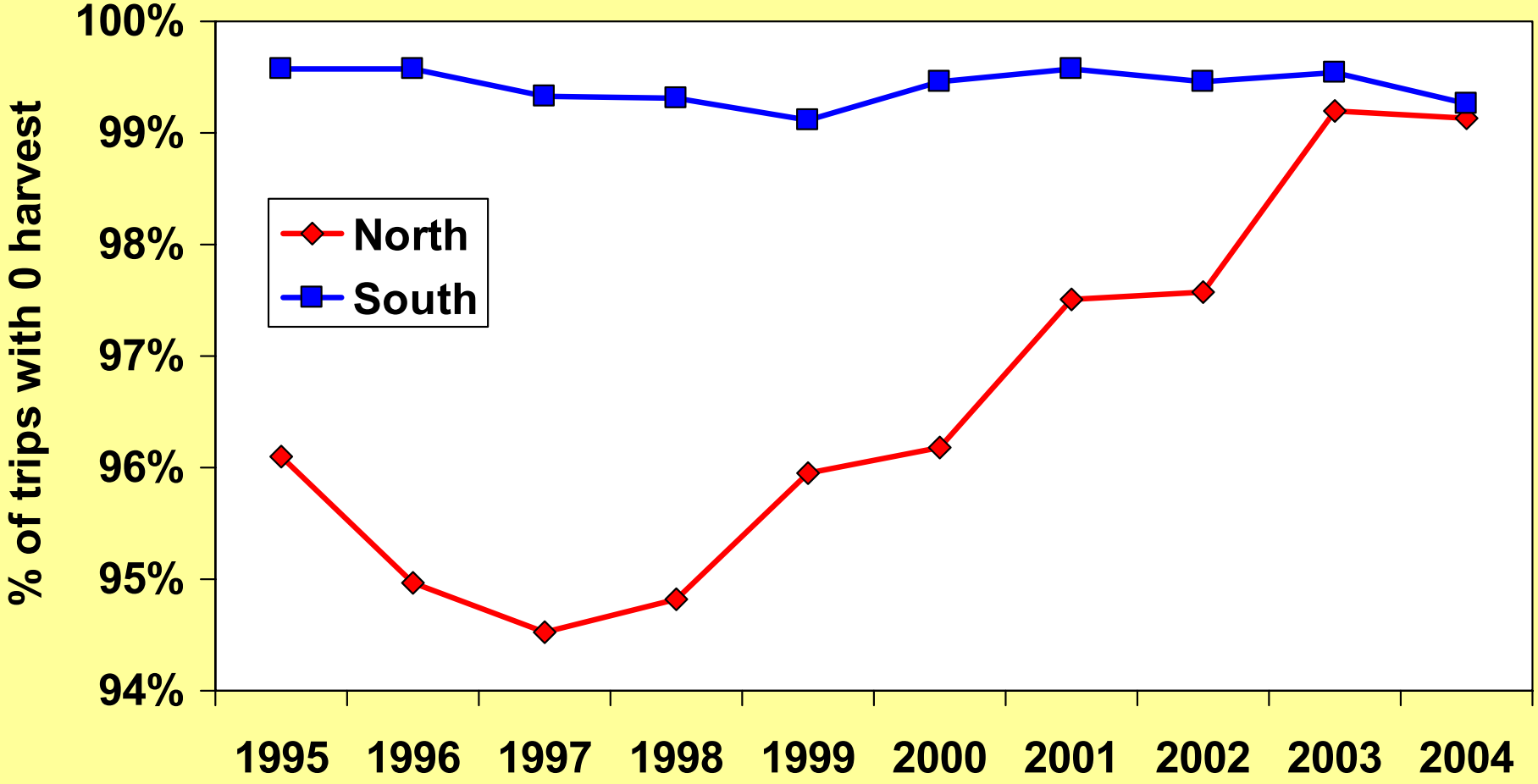
# Distribution of mean 2001-2003 commercial catch and 2004 by gear



# Average 1981-2003 and 2004, 2005 recreational harvest, in numbers, by state



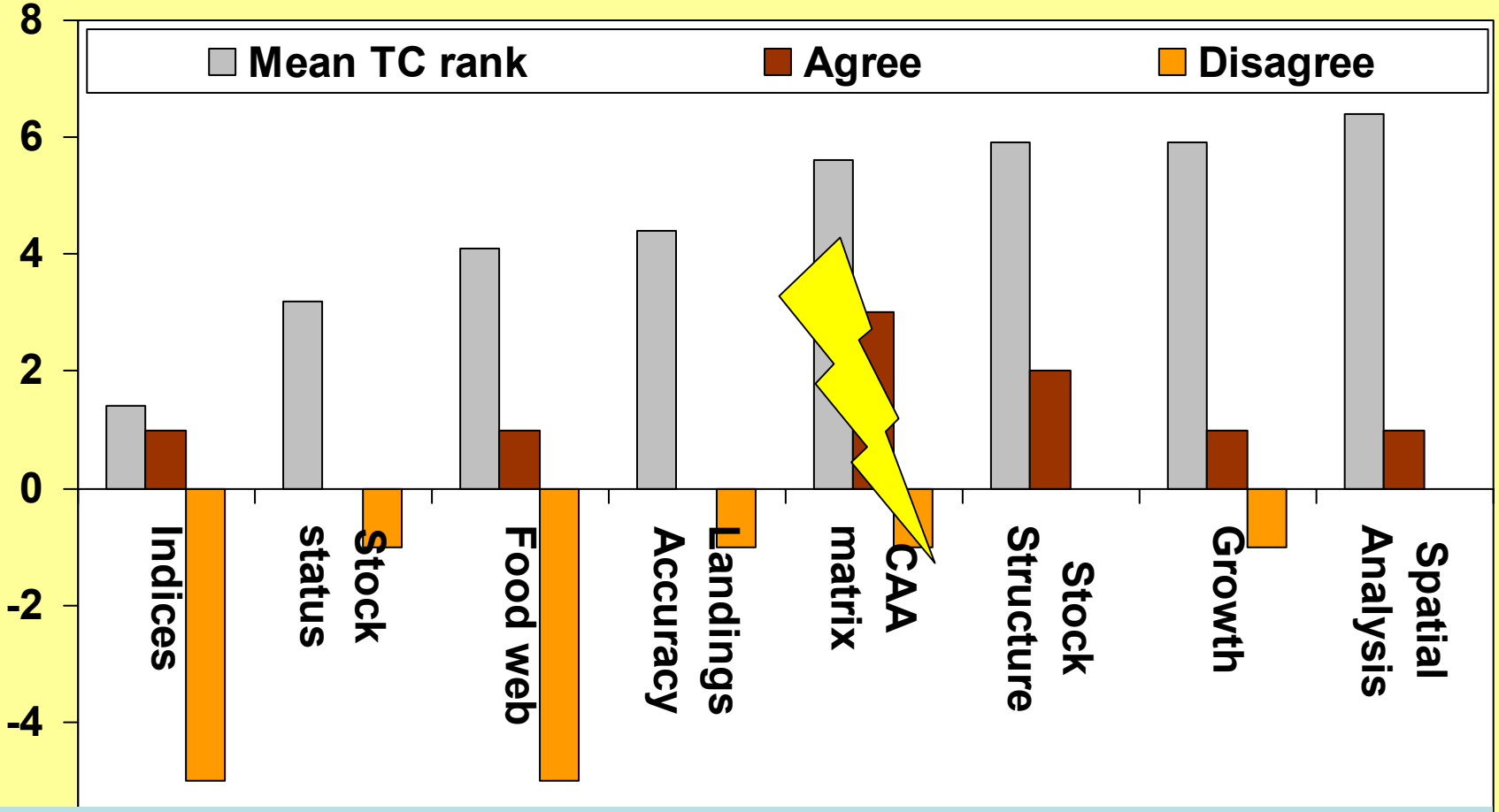
# Percent of all recreational trips in the north (NY-VA) & south (NC-FL) that did not harvest weakfish



# 40th SARC Recommendations

- The TC did not disagree with recommendations
- 6 of 8 recommendations were implemented in the year between reviews
- 2 not implemented required much more time (CAA review) or additional capability (spatial analysis may need GIS to examine anything but gross patterns).

TC agreements and disagreements with 2006 peer-review statements. Lowest mean rank = most important. Agree or disagree displays number of specific statements.




Agreements or disagreements usually unanimous

# Indices – main issue is NEFSC trawl survey vs MRFSS index

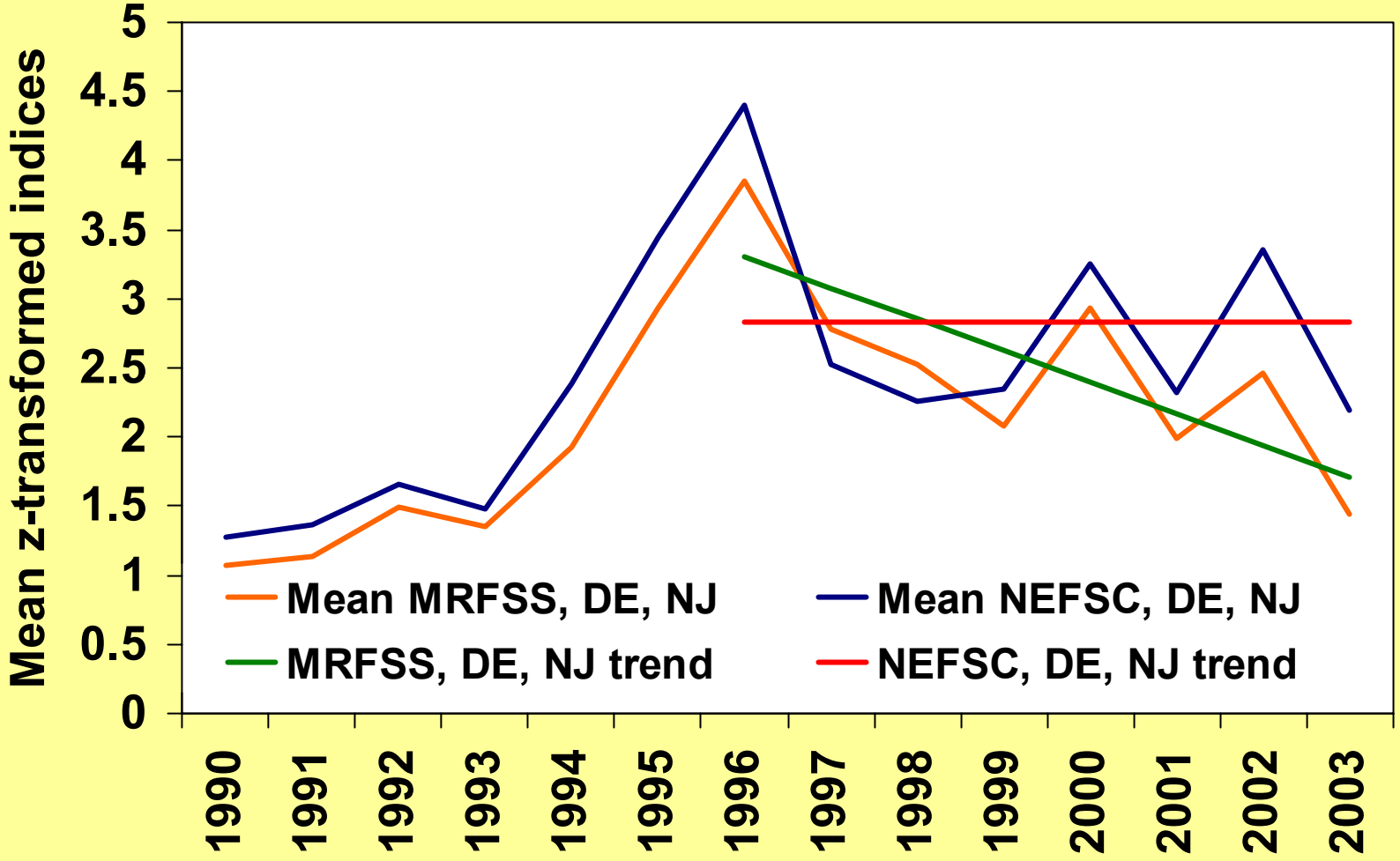
- TC chose MRFSS catch index
- MRFSS index suggested at 40th SARC
- Panel rejected MRFSS – catchability
- TC rejected NEFSC – catchability, spontaneous generation, poor size representation
- Striped bass, bluefish, croaker assessments have MRFSS indices

# Indices – No correlation of MRFSS vs NEFSC
# Disagreement requires choice

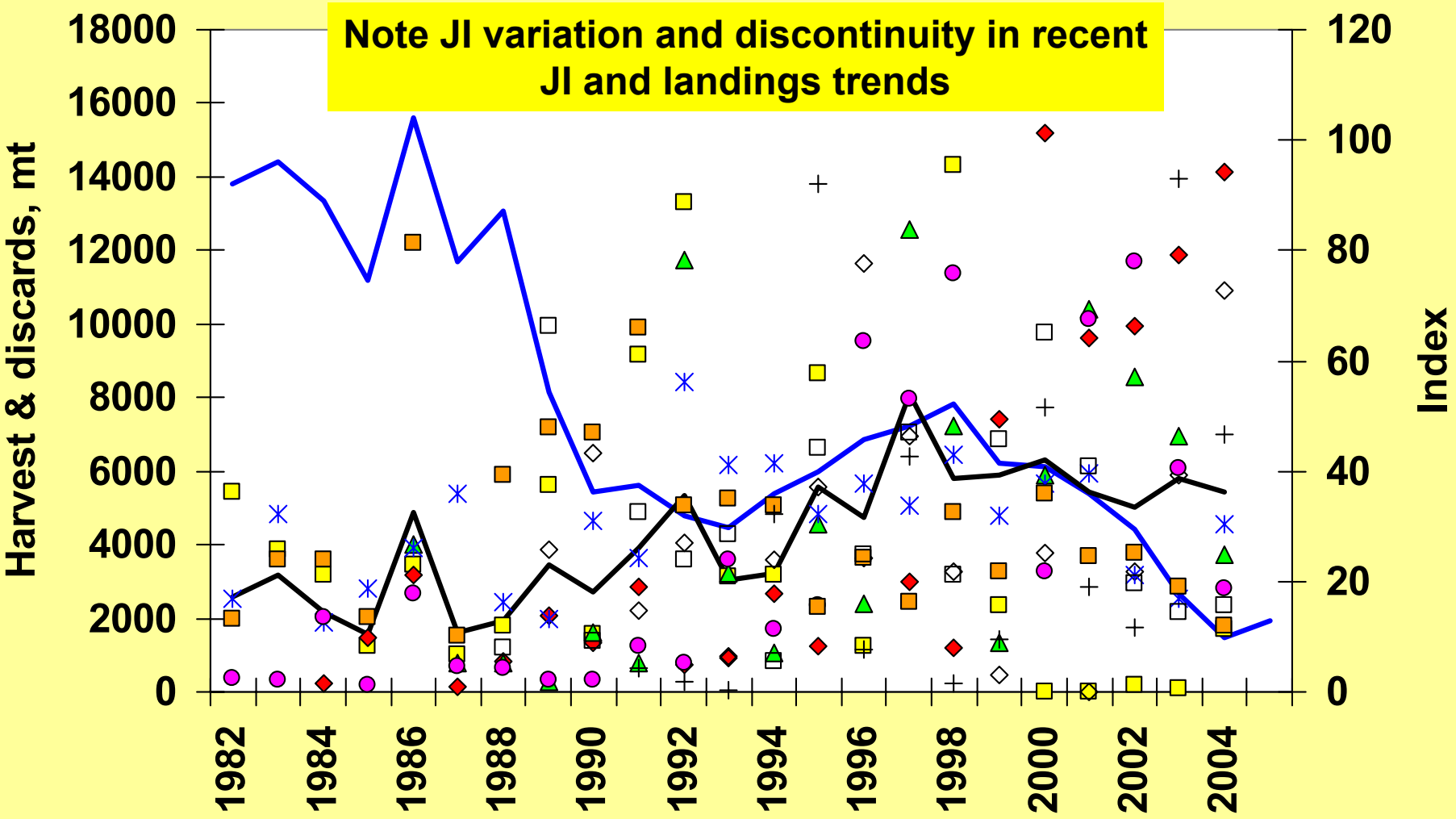
**Green = P <0.05, Yellow= P < 0.10, Red = NS**

| Index | NJ | DE | NEFSC |
|---|---|---|---|
| MRFSS | 0.59 | 0.75 | -0.05 |
| NJ | | 0.78 | 0.66 |
| DE | | | 0.52 |

# Consequences – very different view of recent trend depending on whether MRFSS or NEFSC is averaged with DE & NJ surveys (all standardized)



Increasing trend in JI a cause for optimism? Standardized age 0 weakfish indices versus harvest + discards (blue line). JI grand mean (black line) indicates general JI trend; symbols = different surveys.

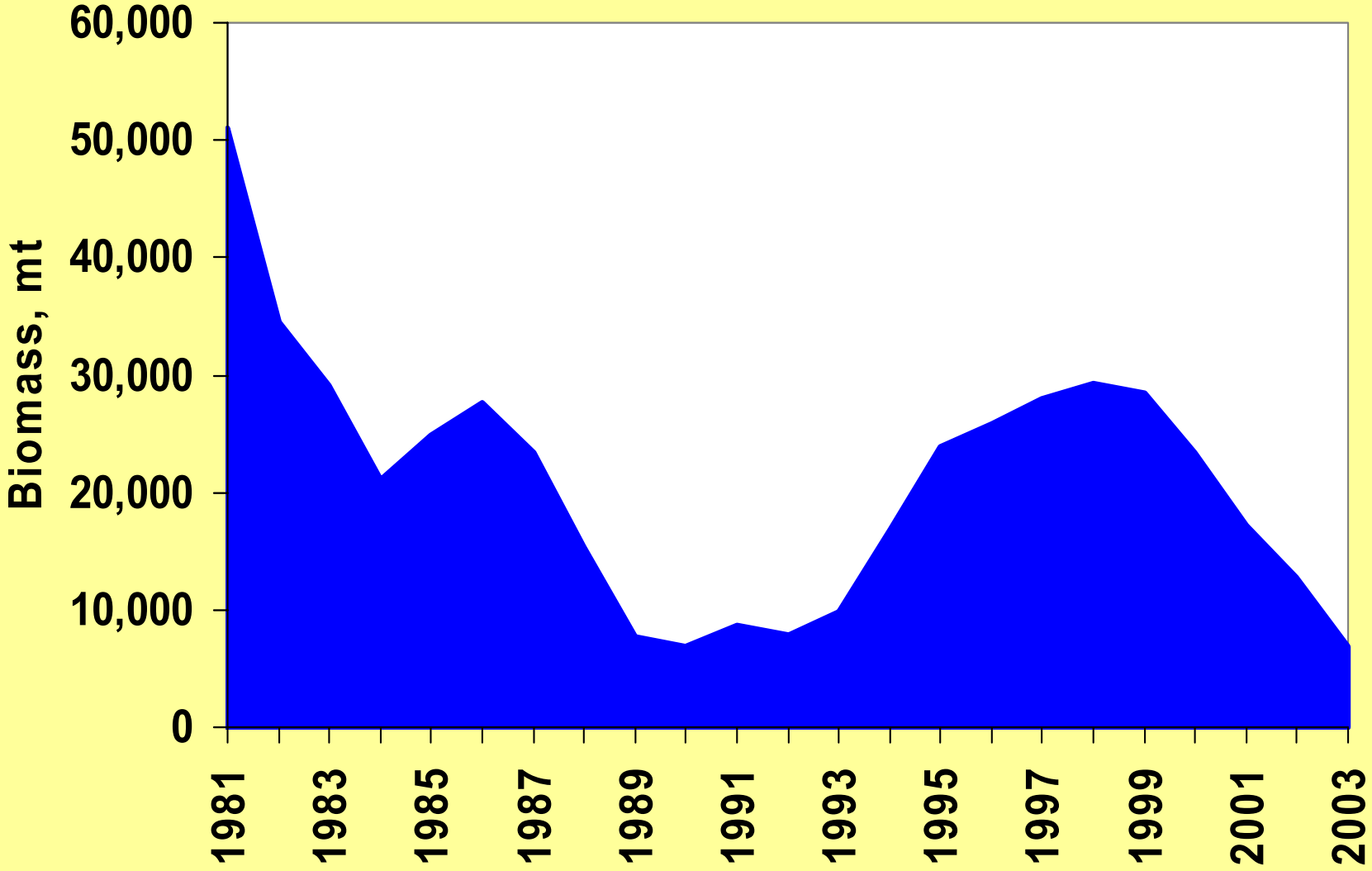


# Stock Status: Review didn't offer view

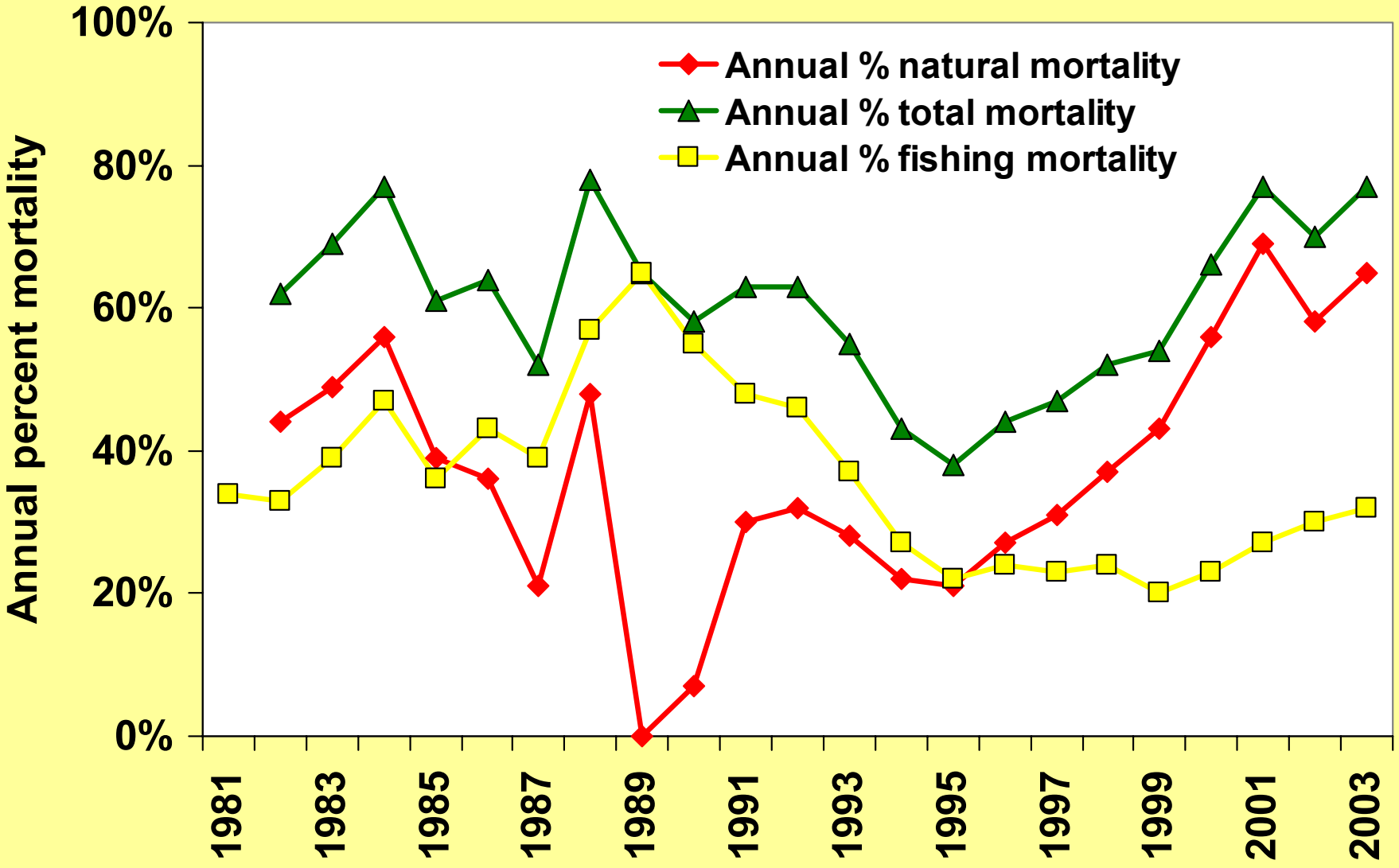
## TC position:

- Stock declining
- Total mortality increasing
- Not much evidence of overfishing
- Something other than F is going on (increasing M)
- Strong chance regulating fishery won't help.

# Estimated weakfish biomass during 1981-2003.



Annual total, fishing and natural mortality. These rates have been translated into annual percentages, so fishing and natural mortality are not additive.



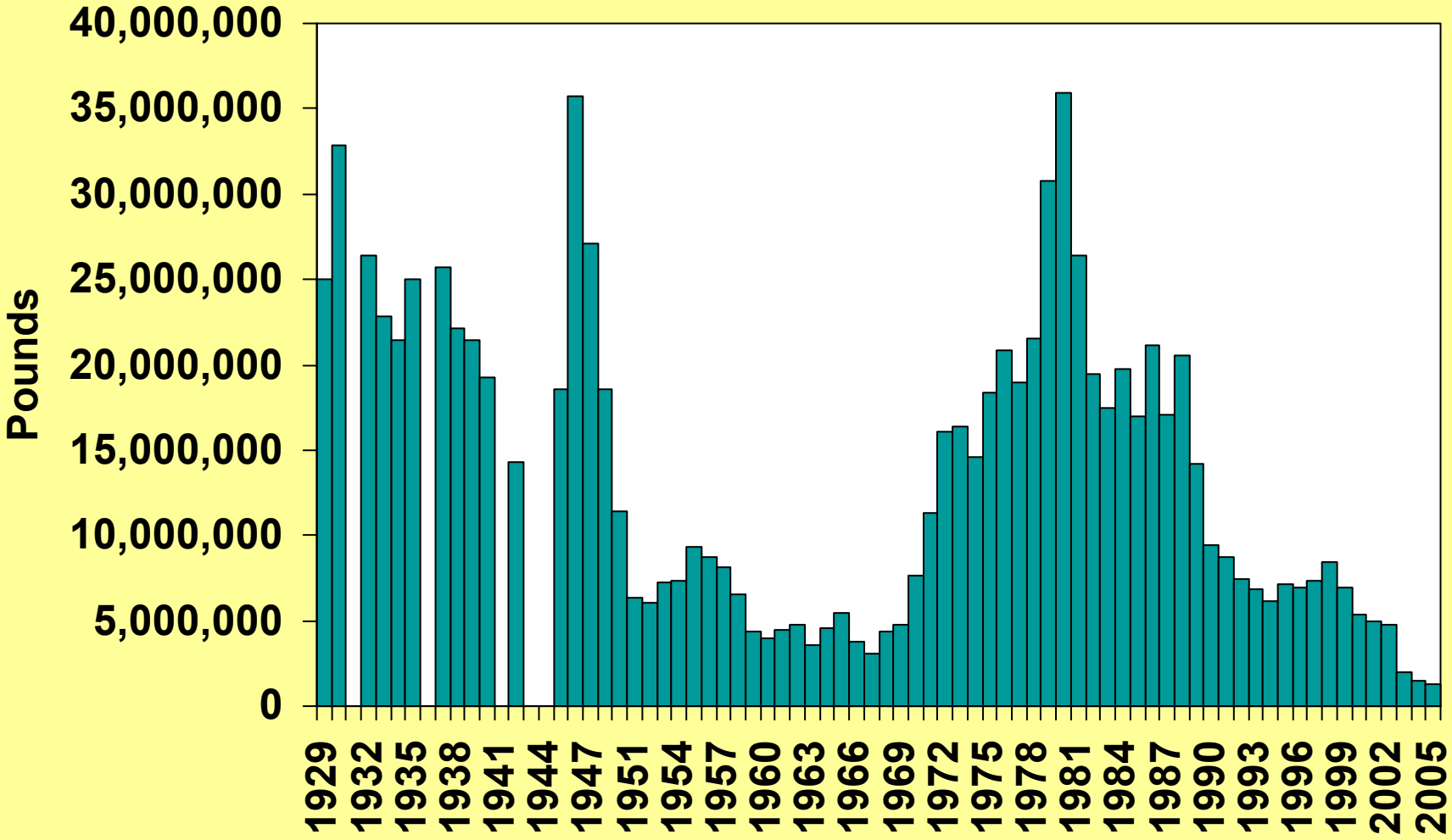
# Major Reason for Decline?

- Neither TC, 40th SARC, nor peer-review implicated directed F as lead cause
- TC considers food-web dysfunction as most plausible contributor to high M
- Panel suggested undetected commercial discards lead to high F
- Food-web or discards indicate little direct leverage on stock and do not present a clear-cut solution

# Food-Web Conclusions

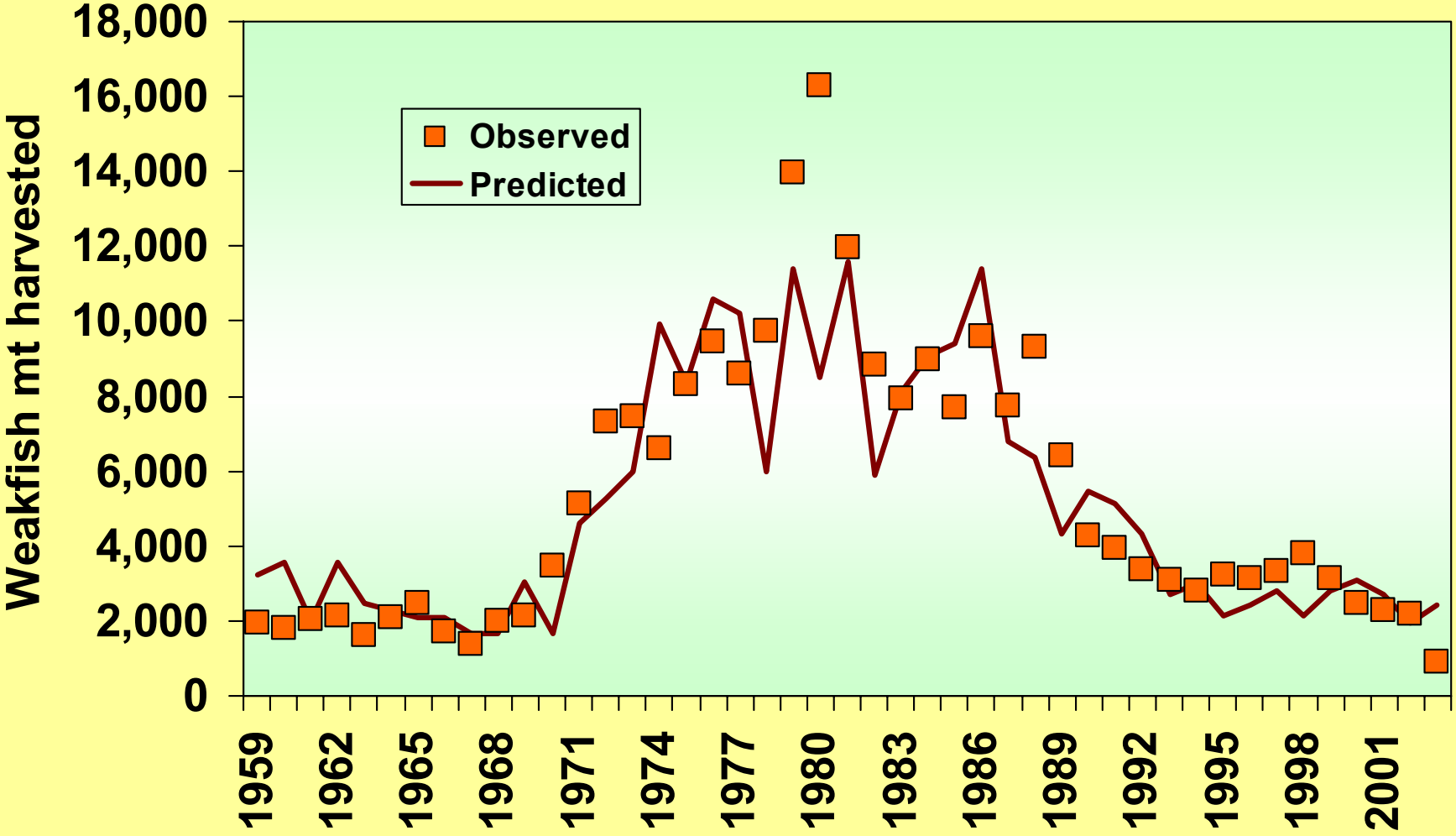
- Diet bottleneck plausible
- High-low weakfish biomass domains evident in long-term landings.
- Now in low domain – cutting F may not allow for recovery because M high.
- Menhaden has large influence over long-term domains.
- Adding bass to single-species model necessary to fit recent decline.
- Bass-weakfish model applies to low domain.

# High-low domains appear in 1929-2005 commercial landings

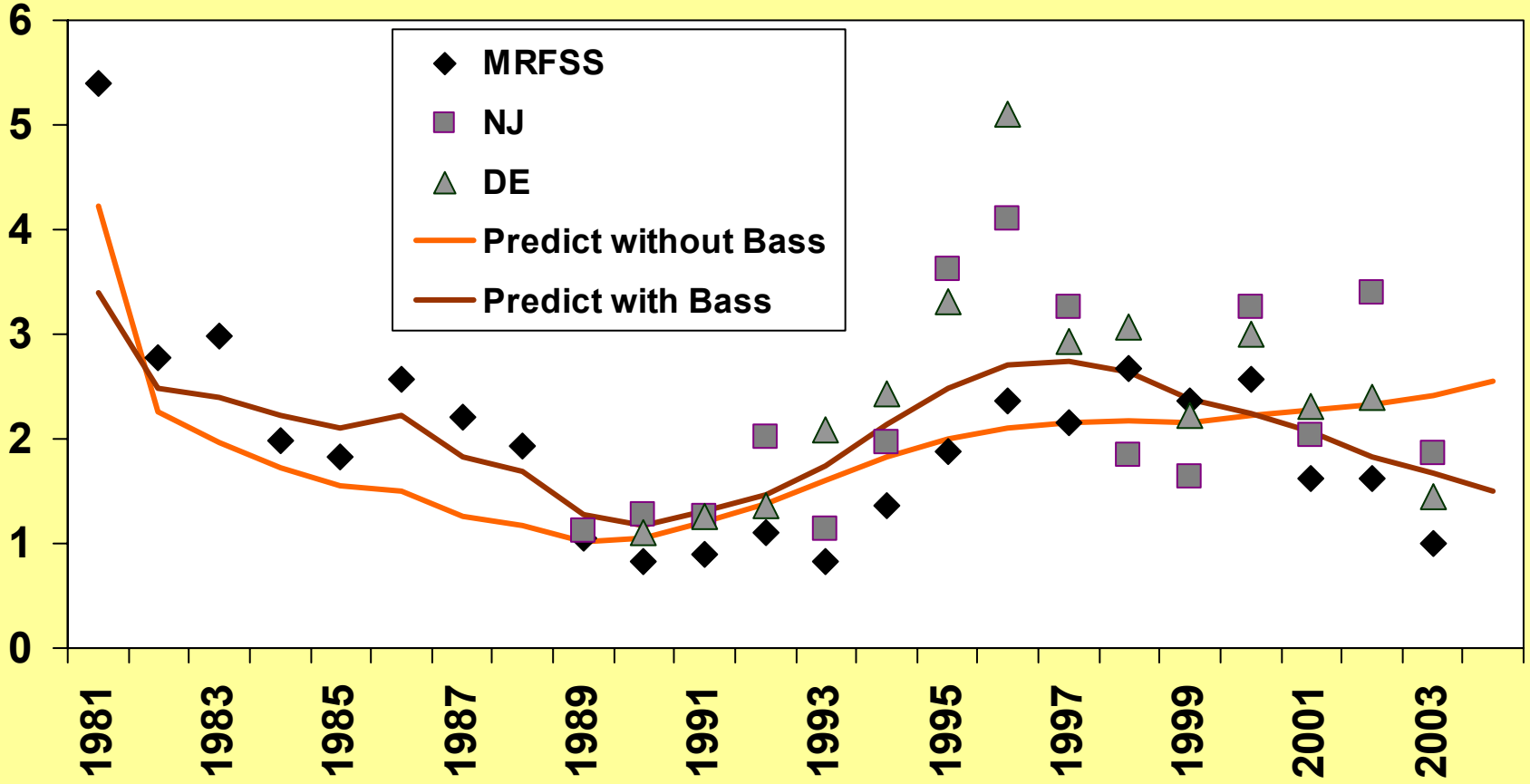


# Food-web. Fit to weakfish commercial landings from multiple regression of large bass index and menhaden juvenile index (both terms significant).

**Menhaden partial $r^2$ = +0.73; bass partial $r^2$ = -0.03.**

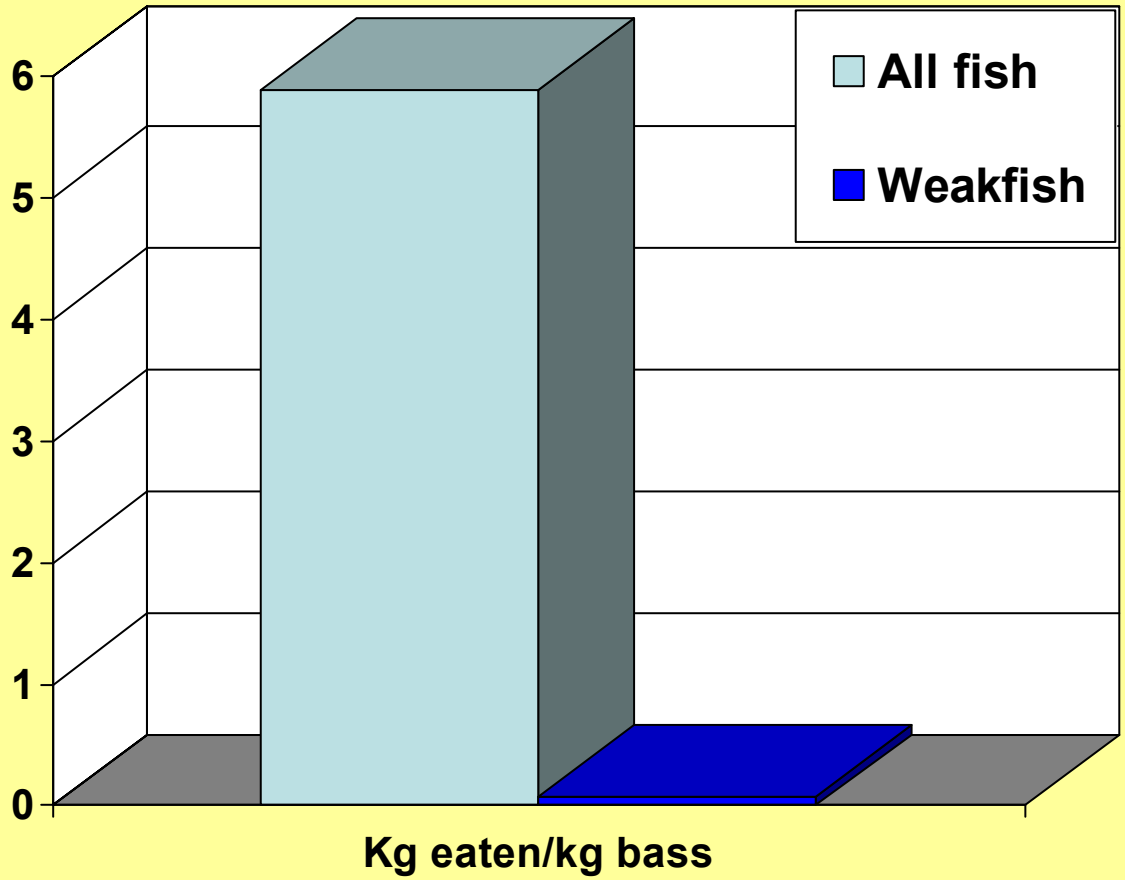


# Food-web. If bass losses aren't included, you don't get a declining trend in recent years. DE and NJ surveys included with MRFSS.



# Food Web –weakfish only need to be a very minor constituent of bass diet.

## Comparison of bass bioenergetics total fish consumption and bass-weakfish model consumption



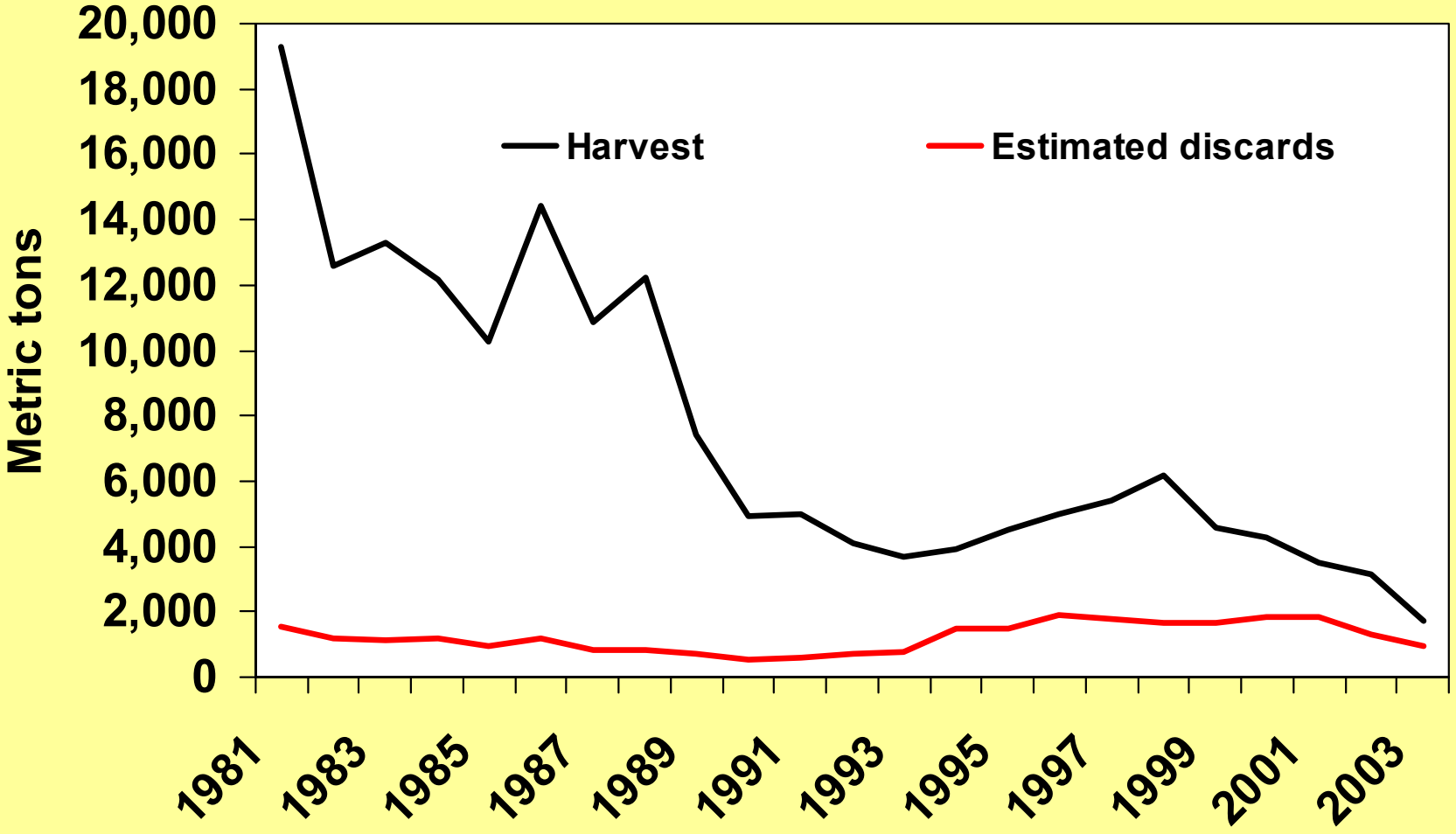
# Landings Inaccurate?

- We use the same commercial and recreational landings as other ASMFC assessments
- Commercial discards estimated by technique used for Atlantic croaker (passed peer-review)
- Recreational ages have to be “borrowed” in any assessment

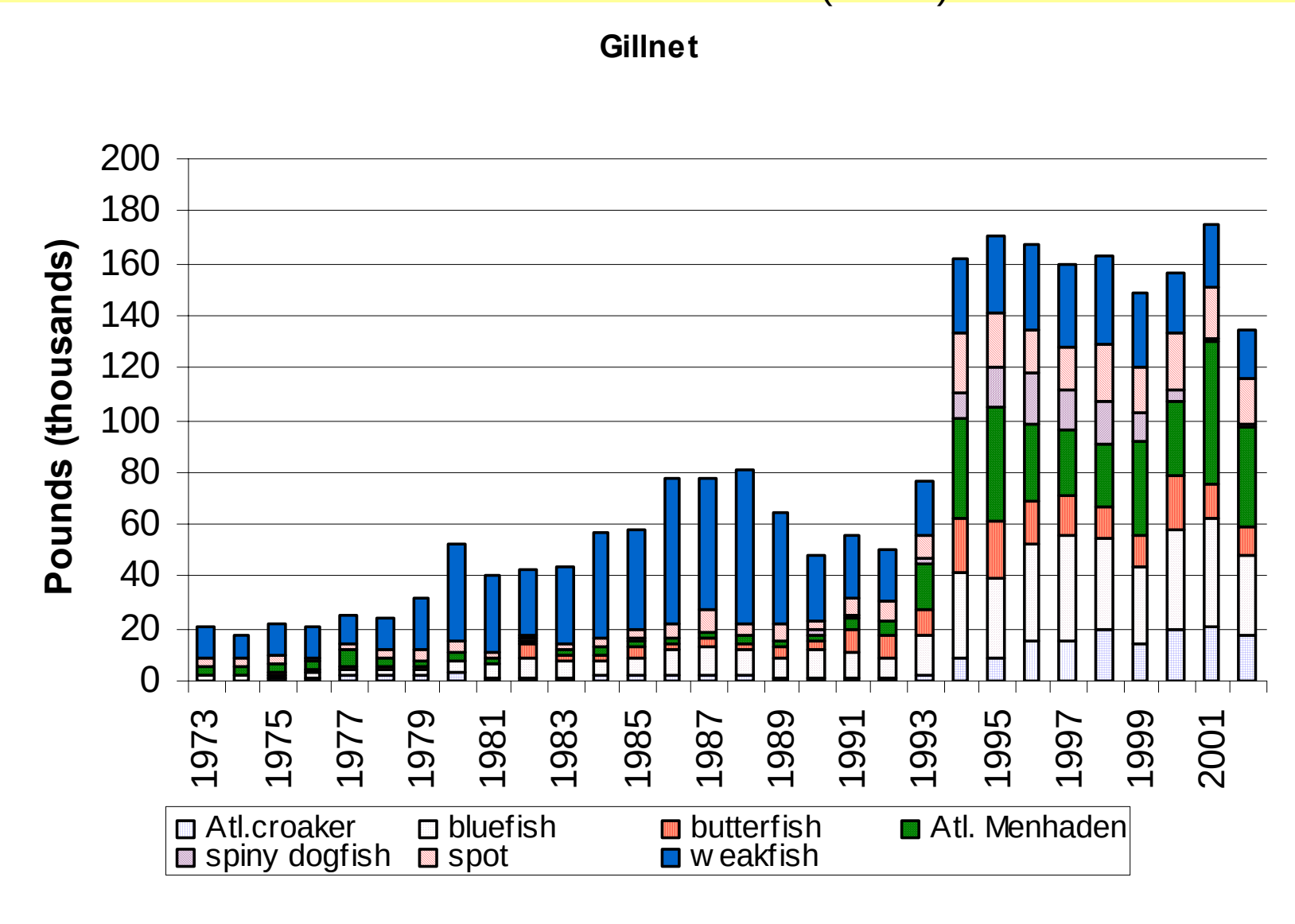
# Commercial Discards

- De Silva (2004) thoroughly estimated gill net and trawl discards during 1994-2003 from ratios of harvest to discards in observer samples
- Precision poor to adequate (95% CI overlaps 0 about 50% of estimates)
- Estimates prior to 1994 estimated from 1994-2002 market discard ratios
- Estimates after 1994 based on market & regulatory discards
- Loss estimates on high side – all commercial assumed dead (+ 20% recreational)

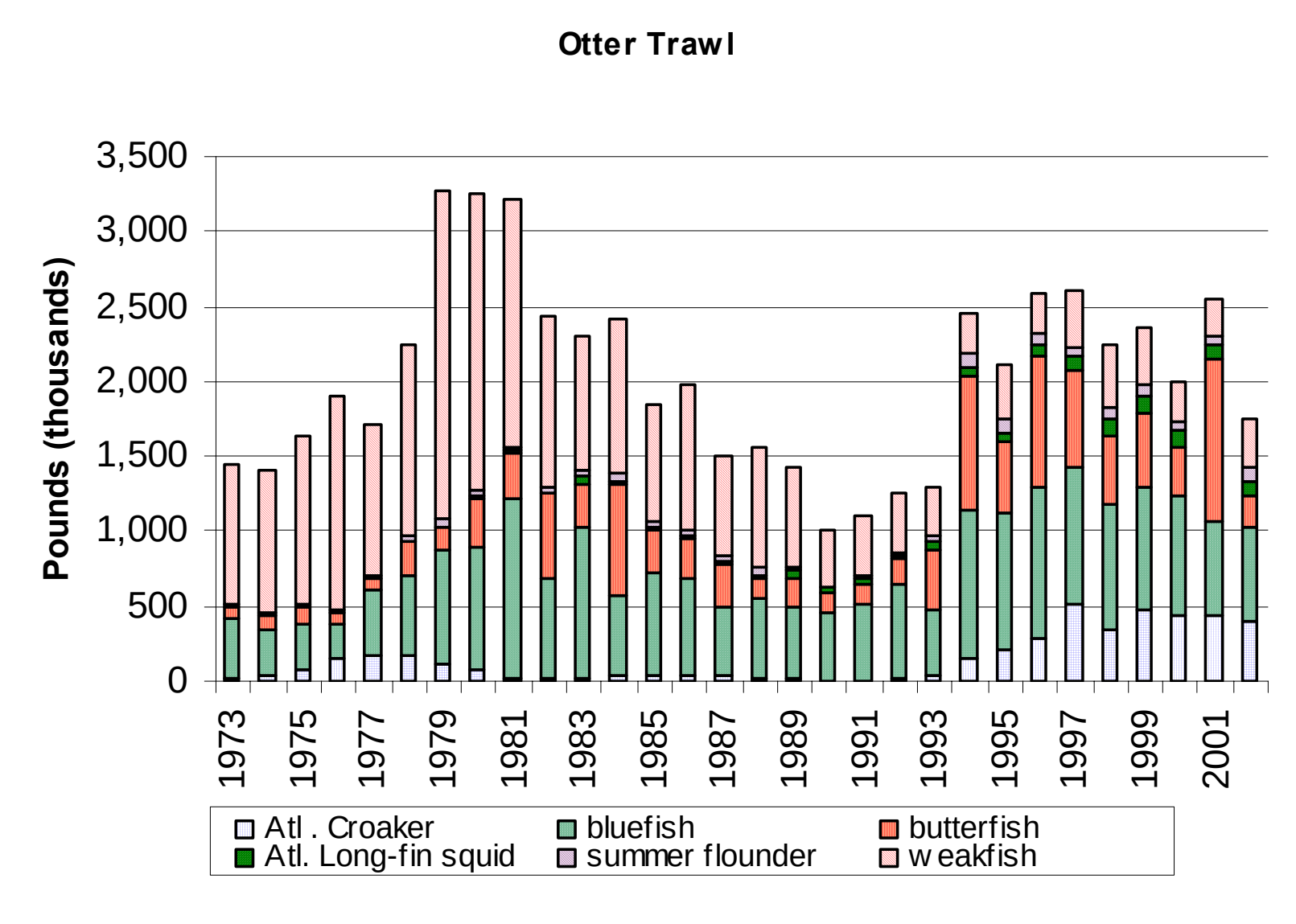
# Reported harvest and estimated discards (recreational and commercial combined)



Weakfish discards from gillnets in the mid-Atlantic by target species. Note discard estimates prior to 1994 were based on non-regulatory discard ratios and include regulatory discards after 1993. From de Silva (2004)



Weakfish discards from otter trawl in the mid-Atlantic by target species. Note discard estimates prior to 1994 were based on non-regulatory discard ratios and include regulatory discards after 1993. From de Silva (2004)

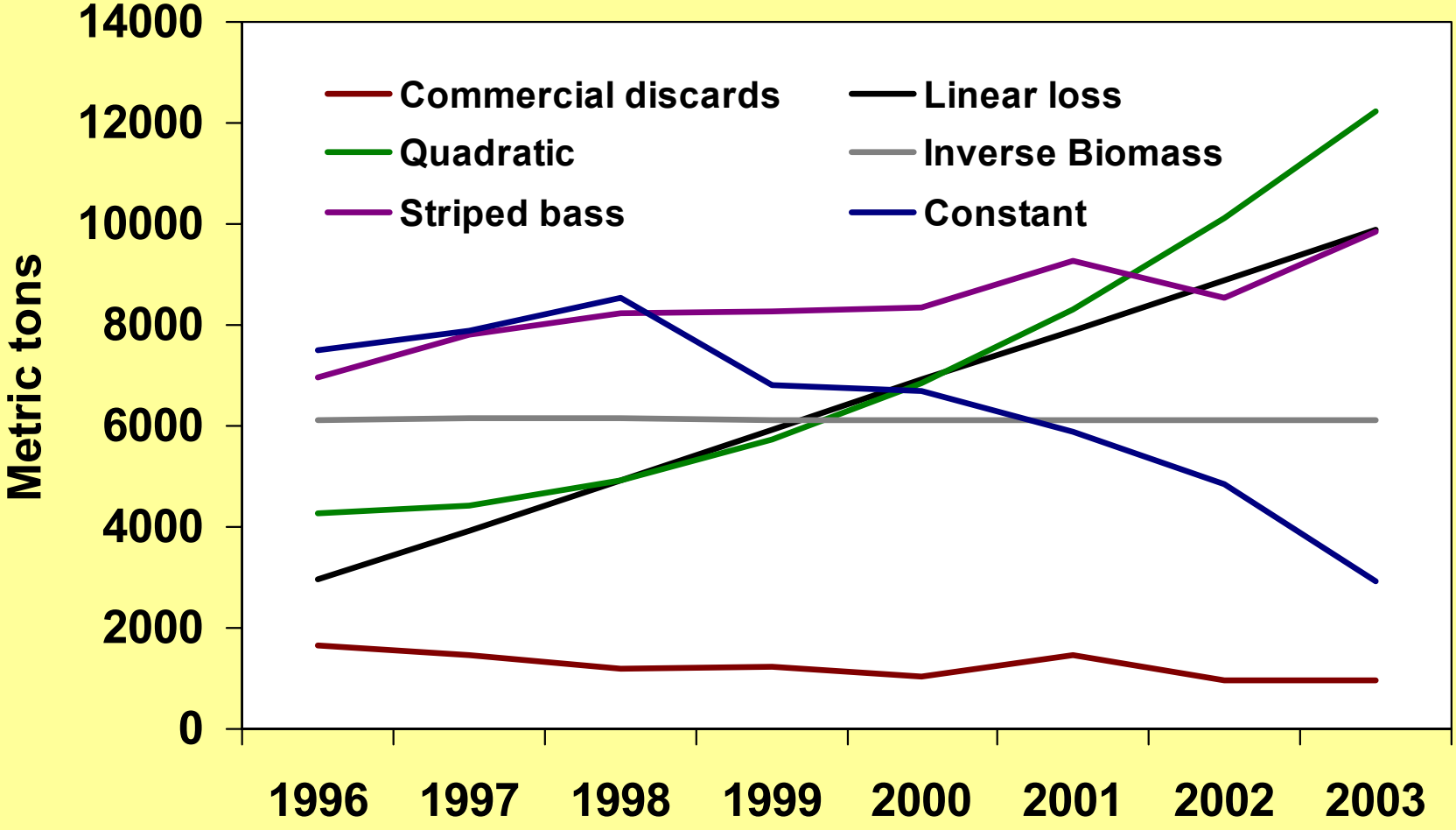


# How much commercial “ghost” discard loss do you need to produce a decline?

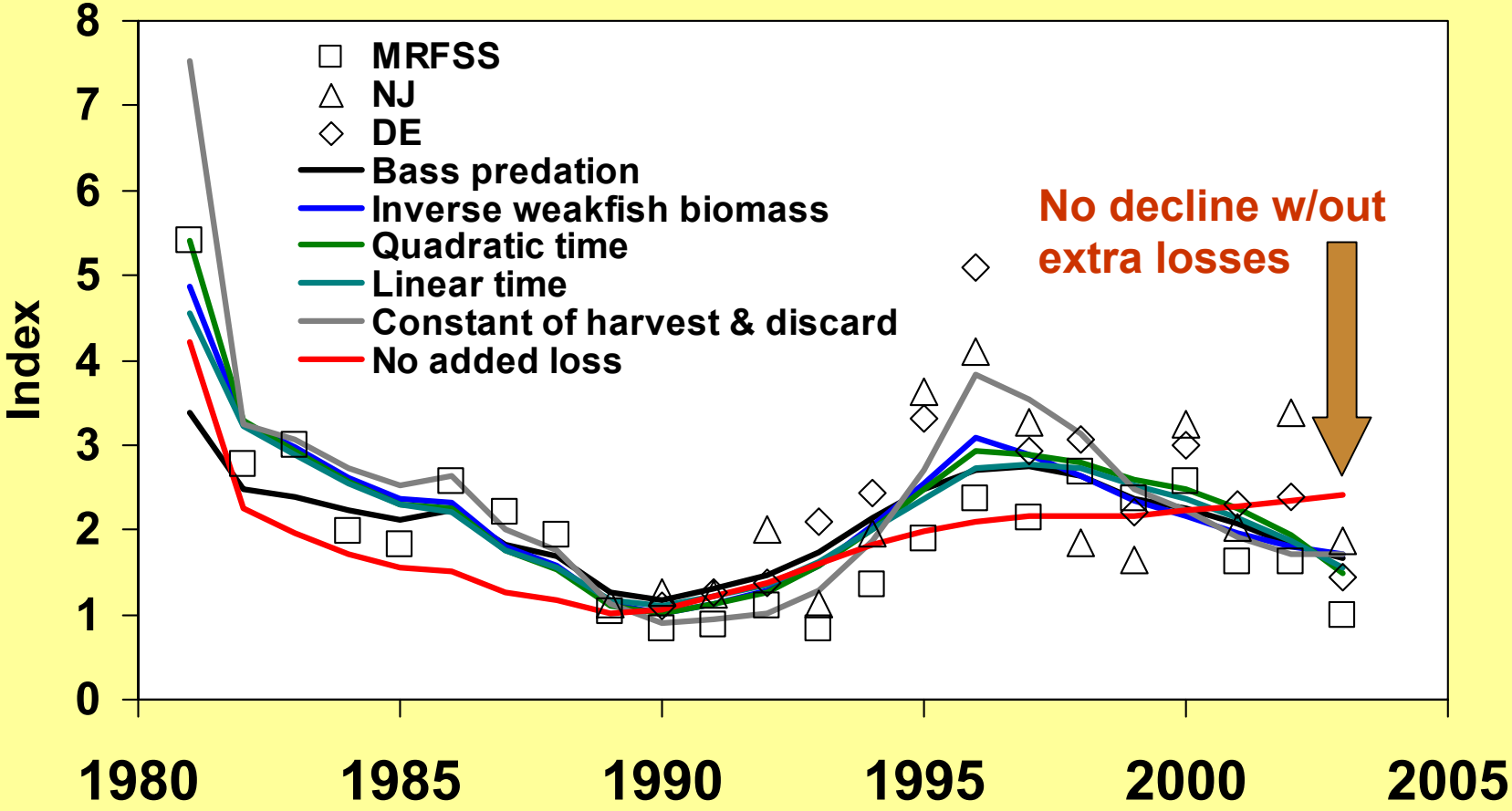
- Peer-review postulated unmeasured commercial (“ghost”) discards as explanation for decline.
- Biomass dynamic model with generic additional losses (time trends, fc of current losses, inverse biomass) tested hypothesis.
- Contrast with no extra loss and striped bass predation
- Used MRFSS, NJ & DE biomass indices.
- “Ghost” losses modeled to start after Amendment 2 (begin in 1996).
- Produce range of possible estimates.
- Search for fisheries capable of producing them.

# “Ghost” losses needed to create decline compared to estimated commercial discards.

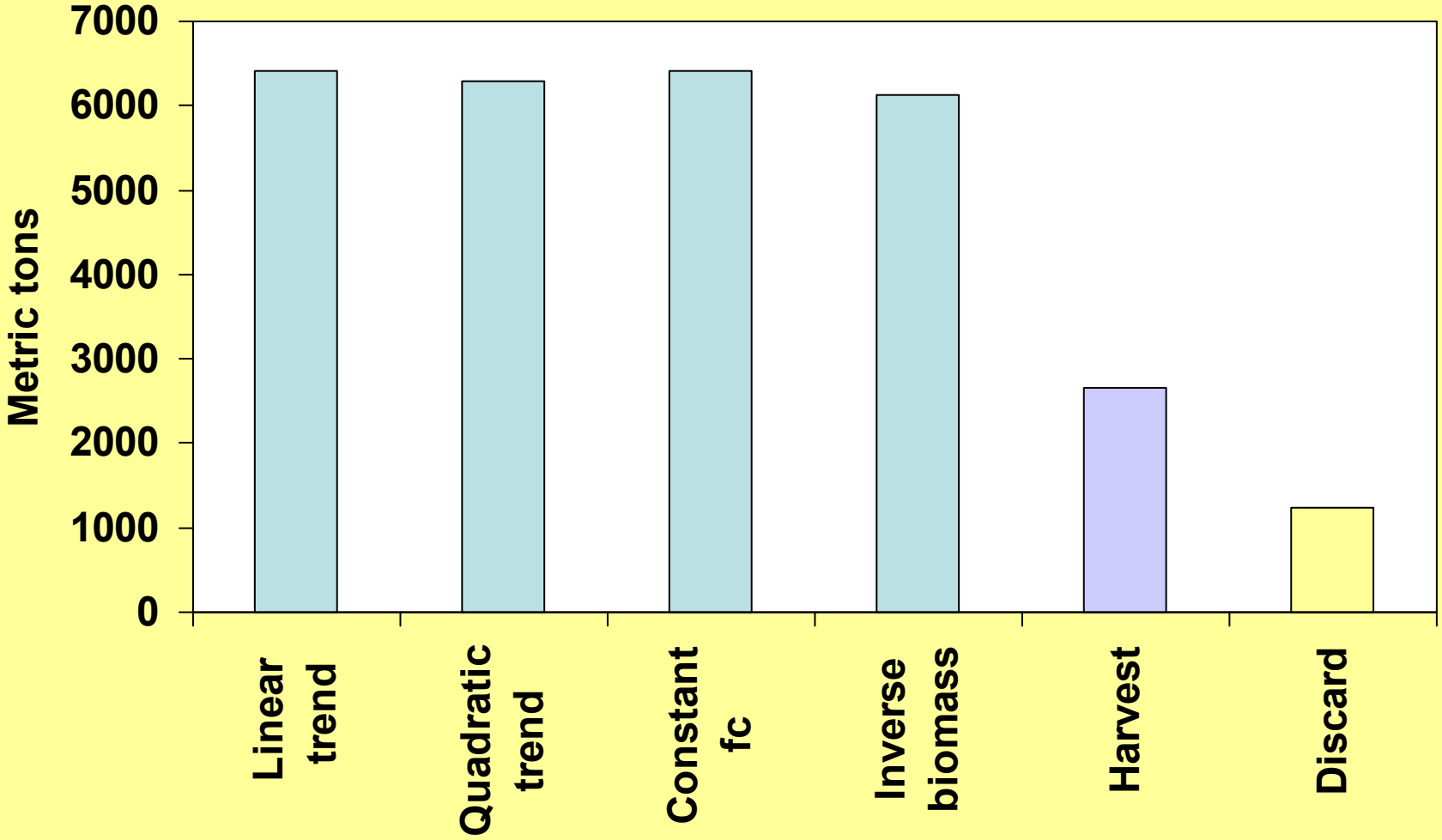
**All fit about the same ($R^2 \approx 0.6$).**



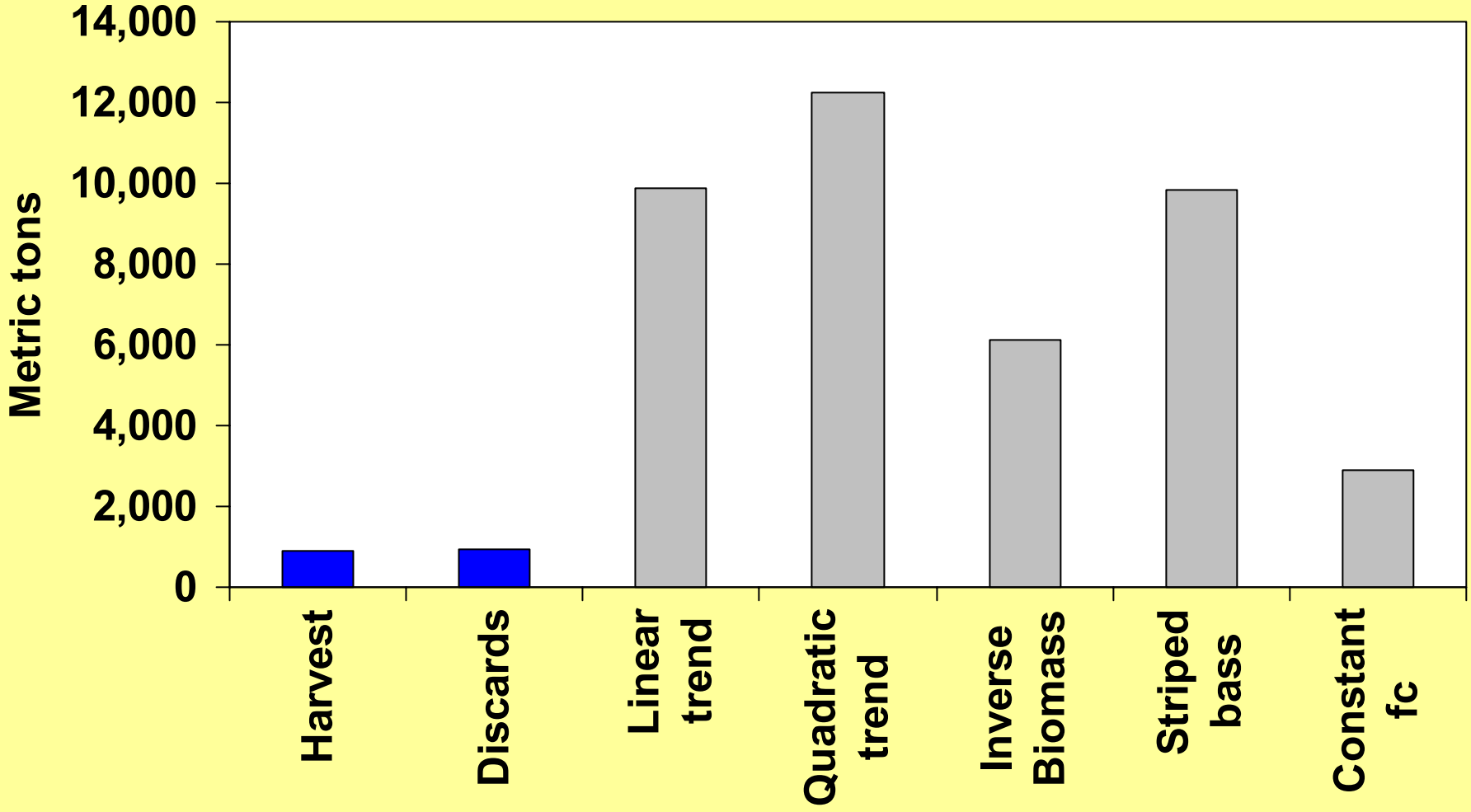
# Fit of biomass dynamic model using original harvest + discards with and without additional loss functions. MRFSS = private boat catch per trip index; NJ and DE are trawl survey indices.



# Averages of 1996-2003 commercial "ghost" losses from models, observed commercial harvest, and estimated commercial discard losses



# Metric tons of additional losses in 2003 from different loss scenarios contrasted with commercial harvest and discard estimates



# Discard models - conclusions

- Discard losses needed to create decline manifold higher than estimated discards
- Little $ incentive for harder fishing that would lead to this magnitude of discards
- TC could not offer candidate fisheries
- Other species should be showing same symptoms

# Ghost Discard Management Conundrum

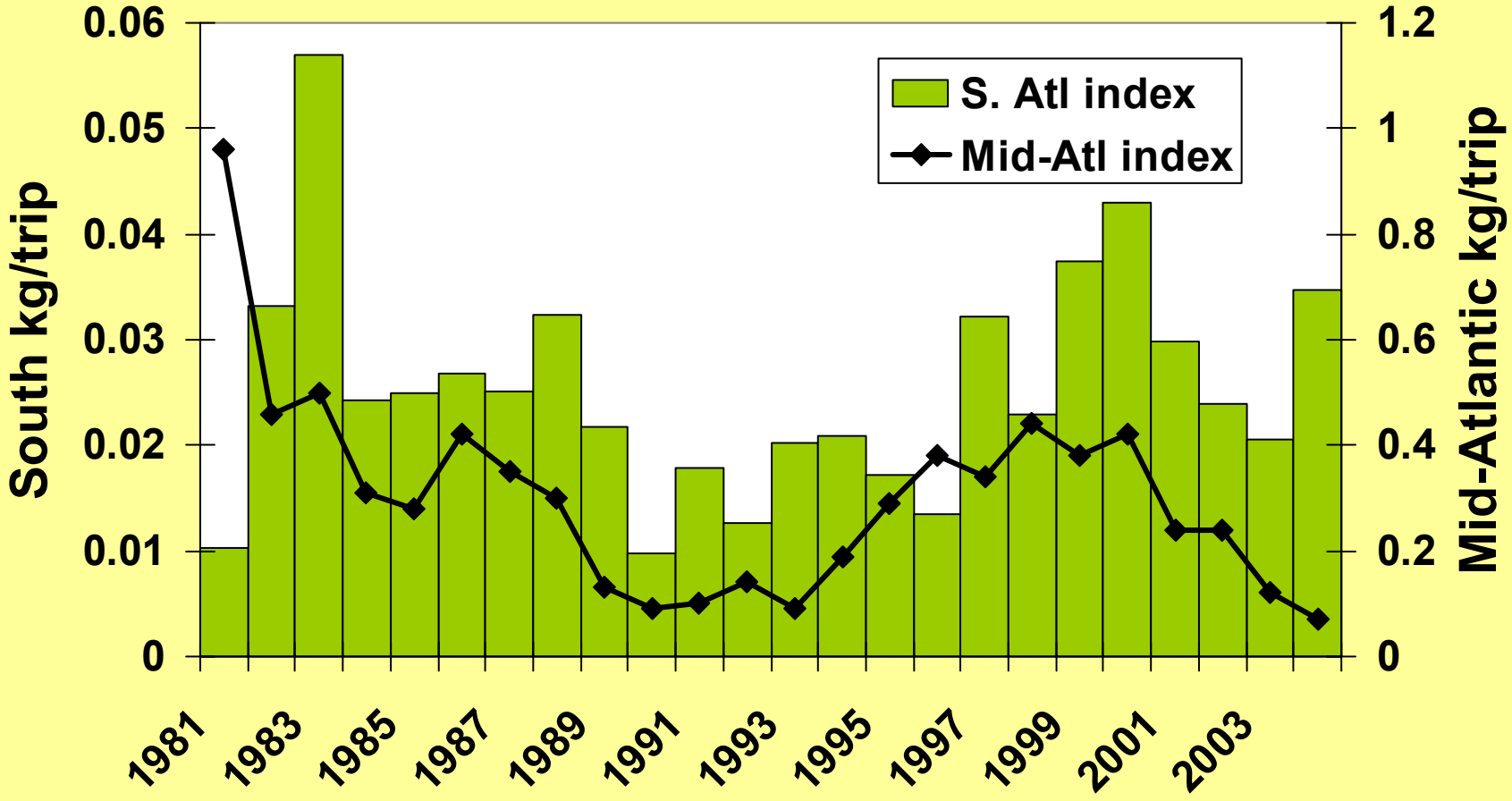
- If “ghost” commercial discards are responsible for decline, then they likely resulted from increased regulation starting with Amendment 2.
- How will more regulation, short of stopping fishing on all species, stem a decline created by regulation?

# Stock Structure

- Is there enough evidence to recommend that the Board consider a split?
- If so, what difference would be suggested?
- Where should the split occur?

# South versus mid-Atlantic relative biomass indices suggest different trends

(MRFSS; mean weight harvested * catch per private boat trip; includes releases)



# Genetic analyses indicate homogeneous stock

**Tagging, otolith microchemistry, meristics, and morphology indicate stock structure**

This information was reviewed by the Technical Committee in June 2005 and 2006

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The Technical Committee declined recommending a north / south split on both occasions.

# June 2006 TC Meeting

- Evidence of stock structure exists.
- Data inadequate to define structure
- Enough potential mixing, can't pinpoint N/S split.
- If north to mid-Atlantic stock is in serious decline, this does not warrant split based on conservation concerns.
- Board needs to clarify reasoning for split.
- Does the Board want stock structure research recommendations from the TC?

Working Paper 5

# Weakfish
# Questions for Review Panel

Data Poor Stocks Working Group Meeting
December 8-12, 2008
Woods Hole, MA

*This information was distributed solely for the purpose of pre-dissemination peer review at the December 2008 Data Poor Stocks Working Group Meeting. It is not being formally disseminated by NOAA and it does not represent any final agency determination or policy.*

**WEAKFISH WP#5 (11/24/08)**

**--FOR PEER REVIEW ONLY--**

# Questions regarding the Weakfish Stock Assessment, for the Data Poor Working Group Review (12/08)

**Abundance indices**
- Does strong correlation of recreational indices using various effort estimates justify use of simpler method?
- Please provide input on criteria for selecting and eliminating "final" tuning indices.

**Analytical methods**
- Should terminal year estimates be presented for management if catch at age modeling is known to produce a retrospective pattern? At what level of retrospective change would terminal year estimate be considered unreliable?
- Discuss merits and drawbacks of using re-scaled relative F and other methods to estimate F, biomass, and abundance in recent years (*i.e.* to eliminate retrospective pattern).

**Non-equilibrium**
- Analyses explored discrepancies between surveys, landings, and anecdotal info indicated factors other than F might be driving the population. Provide insight on analyses that allow judgment of the likelihood that equilibrium or non-equilibrium assumptions are being met?
- Is there sufficient evidence to support the conclusion of increasing natural mortality? Please provide suggestions for methods to evaluate the assumption of constant M.
- Please provide input on incorporating ecosystem (*e.g.* predation) losses into an age-structured model.

**General**
- Suggestions to strengthen assessment (research, analyses, methods).